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Using Real-Time Location Systems & Simulation Modeling to Improve Healthcare

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To the Graduate Council:

I am submitting herewith a thesis written by Colby Thomas Mattie entitled "Using Real-Time Location Systems & Simulation Modeling to Improve Healthcare." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Industrial Engineering.

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Using Real-Time Location Systems & Simulation Modeling to Improve Healthcare

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Abstract

In the healthcare industry, facility managers often find themselves with limited resources, lack of timely data, and unexpected crises that they have to respond too. Their options are based on hastily made assumptions and a limited understanding of all implications of the problems at hand. This scenario has become a concerning issue for the healthcare industry where problems can arise at any time and every minute counts. The healthcare industry is also littered with wasteful processes and regulations that increase the cost for physicians and facility operators and decrease the overall care for the patients. This is very evident in the patient tracking, scheduling processes, and in the scheduling systems that monitor patients while they are receiving care or undergoing tests. While this type of technology does offer improvements, it lacks the direct feedback that the patient needs to eliminate “the lost in the maze” effect that most patients feel while they are waiting. The uses of a real-time location system (RTLS) to track the patient flow and their scheduled procedures can also identify needed resources and optimally match them to patients throughout a health care facility. While the use of an RTLS is an improvement, it isn’t enough to dramatically improve healthcare to the level it needs, or to provide valuable real time data to the administrators who use the system to track, treat, and report both the patients’ progress and their current status. The implementation of simulation patient models can provide real time patient data regarding where the patients are within the system, where they are within the patients scheduled procedures, and where the patients next expected procedure will be. This data can be integrated with all the patients corresponding schedules and the availability of the staff and equipment to provide up to the minute status for the physicians, administrators, patients, and love ones. By combining an RTLS with a simulation model, health care providers

can harness real-time data that is input into a model to help optimize the present situation and perform "What-If" analysis and create improved data visualization.

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Chapter 1 Introduction

The ever rising cost of health care has become a very expensive necessity. This often puts many people from all age groups and demographical regions at risk because they cannot afford the cost of preventive care or the cost of needed procedures. The cost associated with healthcare in the United States has become an important issue and is currently rising faster than average wages and inflation. [1] These increases have forced 58 percent of patients to postpone and or to go without healthcare. [2] In the United States, the cost of healthcare consumed 17.9 percent of Gross Domestic Product (GDP) spending in 2011. [3] Healthcare spending is expected to rise to $4.4 trillion by 2018. These rising costs will consume a fifth of nations GDP. [4] The amount of people that can't afford healthcare has risen to an unacceptable level, and a method of reducing these costs must be found. The cost associated with new medical technology, research and development, pharmaceutical development, and the overall cost of both physician and facility malpractice insurance are major factors for the continued rise in health care cost. Resource utilization therefore has become a major focus in keeping the overall cost of health care low. The health care industry has begun to utilize several different improvement techniques regarding resource utilization with mixed results for the facility/physician and for the patients. Increasing the affordability of health care through efficiency is not just beneficial to the patients but to the overall healthcare industry as well. Health care facility operators can expect to see decreases in their overall operating cost as a result of the implementation of an RTLS in their facility. These savings will be attributed to better scheduling control of needed staff, better utilization of the prime procedural rooms and their associated equipment, and faster response time to emerging crises through resource leveling. All of these savings will increase the level of patient care and yield substantially higher year to year profit for both the physician and the health care facility.

Healthcare institutions are constantly working to improve the quality of care for all of their patients. With the high volume of patients, high wait times, and the pressure from the insurance providers to reduce the time spent with each patient, the perception of poor quality care for the patient is becoming an increasingly important issue for healthcare facility administers. [4]

Chapter 2 Problems Definition and Formulation

In the healthcare industry, keeping patients on schedule is critical to meet both the patients expectation of quality care, and to meet the facility's goal of a well ran/ profitable facility. Most facilities over book their capacity in order to ensure a steady flow of patients and to keep staff fully utilized. Overbooking is done to compensate for patients who arrive late, or who forget their appointment completely. While this does ensure a steady flow of available patients, it all too often creates confusions within the facility when backups occur. The results of these backups are patients who have to endure long processing times and staffs that become stressed do to the increase work load. The ability to keep track of all the patients can have a great impact on the performance in a clinic or hospital. Healthcare facilities are sometimes broken down into sections and the flow of patients between these sections can create confusion which results in inefficiencies throughout the system as a whole. When each section only considers itself and doesn't consider the performance of the entire system, bottlenecks and underutilization of resources can occur. Without a way to look at the entire system these problems will continue. The inability to track the flow of the patients and the resource utilization of the facility makes it hard to make intelligent decisions regarding on the cuff schedule changes. Decisions made in this manor can put the patient at risk and is unacceptable practice. While experience is a good thing in the healthcare field, it can lead to a manager trying to solve problems in traditional ways instead of newer, more efficient ways. Managers currently have to make decisions based on experience and feeling rather than data because there is usually little to no data available. Even when there is data it is usually outdated or too limited to make an impact. This lack of data driven decisions can lead to wrong choices being made and limiting the capacity of the facility.

Section 2.1 Math Model

A major issue in the healthcare industry is scheduling patient to create the optimal throughput. Healthcare facilities usually have a daily schedule that is broken up into time slots to which each patient is either assigned or given a choice of available empty slots. Since patients come for a variety of reasons the time needed to treat them varies. Considering all the time slots are in same time units, wait time build up when patients with longer treatment times arrive. This method shows a flaw in the typical healthcare scheduling system. Not only do healthcare facilities care about patient throughput, they also care about the profitability of the facility. So a scheduling system that optimizes throughput and maximize profits would be ideal.

To improve the current scheduling system, a math model was created to help maximize the throughput by rearranging the scheduling by the different patient categories. Since different categories create different revenues and have different treatment time, the model solves for the optimal balance depending on the forecasted demand.

Math Model

Indexes

- i – Patient category
- t – Time slot
  - i.e. Monday, Tuesday, Wednesday, …. or smaller time units.
- Sets
- R_{it} - The Revenue made from patient category i in time slot t
  - This can be the same number each time slot but can change under circumstances where certain time slots have increased costs and lower revenue

- Z_{it} - The treatment (processing) time for category *i* to complete their procedure in time slot *t*
- Q_i - The total demand of category *i*
- C – Cost per time unit
- T – Time allowed in each time slot
- Parameters
- μ_{it} – Percentage of category *i* that must be seen during certain time slots
- w_i – Parameter used for reducing treatment time (Z_{it}) for each category *i*
    - Percent saved by doing multiple procedures
    - Theory: if the same patient category is seen repetitively in the same time slot the set up times will decrease and the Z_{it} will decrease allowing more patients to be seen.
- ρ_i –Parameter that represents the minimal percentage of category *i* patients that must be seen from the category's total demand (Q_i)
        - i.e category *4* must see 15% of the total demand (Q_4)
- σ_i – Maximum percentage of the total patients seen that category *i* can allow
        - i.e. category *2* can only make up 40% of the total patients seen

Decision Variables

- X_{it} - The number of patients from category *i* in time slot *t*

Number of patients in each category seen in each time slot

Optimization Function

Equation 1- <u>Maximize Profit</u>

$$\boldsymbol{Profit} = \sum_{i=1}^{n}\sum_{t=1}^{m} \boldsymbol{X_{it} * R_{it}} - \mathbf{C} * \sum_{i=1}^{n}\sum_{t=1}^{m} [\boldsymbol{X_{it} * (Z_{it} - w_i * X_{it})}]$$

Subject to:

Equation 2 - <u>Demand Constraint</u>

$$\sum_{t=1}^{m} X_{it} \leq Q_i \quad \forall\, i$$

The number of patients seen for each category cannot exceed the demand

Equation 3 - <u>Minimum Category Demand Constraint</u>

$$\sum_{t=1}^{m} X_{it} \geq Q_i * \rho_i \quad \forall\, i$$

Meets the required minimal percentage of demand for each category

i.e. must see 20% of the available patients in category 1 in all time slots

Equation 4 - <u>Maximum Category Constraint</u>

$$\sum_{t=1}^{m} X_{it} \leq \sigma_i * \sum_{i=1}^{n}\sum_{t=1}^{m} X_{it} \quad \forall\, i$$

Limits the amount of patients seen in each category to a predetermined percentage of the total patients seen

i.e. category *4* can only make up 20% of the total patients seen

Equation 5 - <u>Time Constraint</u>

$$\sum_{i=1}^{n} [X_{it} * (Z_{it} - w_i * X_{it})] \leq \mathrm{T} \qquad \forall\, t$$

The sum of the time all the patients seen in a time slot can’t exceed the time allowed in the time slot. (i.e. time in a day)

Equation 6 - <u>Time slot % constraint</u>

$$\sum_{t=1}^{m} X_{it} * \mu_{it} \leq X_{it} \qquad \forall\, i$$

If a percentage of category *i* is required to happen during set time slots.

(i.e. 80% of patient *i* must happen in time slot 1 and 2)

Equation 7 - <u>Non-negative Constraint</u>

$X_{it} \geq 0 \qquad \forall\, i, t$

Number of patients cannot be negative

The model does create a useful tool to aid healthcare facilities but isn’t enough to make the impact needed. The model has a number of assumptions and since healthcare facilities have their differences, the generality of the model constrains its usefulness. The model does not take into consideration other variables different facilities might have so therefore it would have to be modified to fit each individual facility to make a drastic impact. The model is a good base and has potential to make an improvement for healthcare scheduling systems.

Chapter 3 Literature Review

Section 3.1 Lean Principle & Techniques

To help cut waste, some healthcare facilities have begun to implement improvement techniques that have been widely used in industrial manufacturing. The use of Lean Manufacturing and Six Sigma principles in industrial manufacturing have greatly increased their production and profitability by allowing them to cut and reduce unneeded manufacturing steps, by eliminating production bottle necks that waste time and by reducing waste of critical materials and resources. Manufacturers today are far more efficient than they were a decade ago thanks to the adaption of these production improvement principles. Because of this track record of success, some healthcare institutions have implemented Lean Manufacturing and Six Sigma principles to help reduce their waste and improve the overall patient care that they are entrusted with.

The wide spread use of these powerful industrial manufacturing techniques to track and deliver real time data is currently limited in the healthcare service sector. Unlike a factory that produces the same widget each shift, a healthcare facility must receive, diagnose, and treat a multitude of patients with individual needs. The use of Lean fundamentals can be utilized in a several different areas to improve the efficiency of a health care facility. Hospitals and special care facilities can first utilize 5S principles to sort and discard their unneeded materials and to improve both the organization and the standardization of their needed inventory within the patient rooms, procedure areas, and in general, the entire health care facility.

Deploying poka yokes techniques to help manage a healthcare facility has also been very effective in creating an environment has greater focus regarding its required task. This increased awareness has reduced the overall number of mistakes and as a result, has increased the overall value of the care given. By creating a system that reduces and prevents mistakes, creates a safer environment for patients and the staff. By installing poka yokes techniques to the various healthcare operating systems, problems along with the root causes were uncovered before they affected patients. This heads up approach fostered an attitude among the care providers and administrators that reduced the reoccurrence of similar problems. Examples of the use of poka yoke techniques and principles in healthcare would include warning labels for equipment and medication applications that instruct the use and rate in simple to understand terms that make its function easier to operate and less likely to fail. [5] This is very important in healthcare because one unfortunate mistake, such as having a piece of equipment in the wrong storage location or incorrect and incompatible operating instructions on the equipment, could be life threatening

Value stream mapping has also been deployed in health care to a value stream map to visualize the true path of patients, not the ideal path. This Lean manufacturing methodology along with the use of Kaizen principles have been used to sort the value added activities from non-value added activities which cut out unnecessary steps and in turn, makes the process more efficient. The use of Lean Thinking techniques created more efficient work flow paths by pairing patients by length of stay to the facilities that they needed. The idea that every patient is unique is true but 6 percent of procedures account for 50 percent of the work load. [6] The application of Lean principles in healthcare has provided improvements in different areas and aspects.

Six Sigma has also played an important role in the improving healthcare. The ability to reduce errors and to reduce variation in how procedures are performed by performing root cause analysis can cut cost in different areas throughout a healthcare system. Below are a few example of where Six Sigma practices reduced wasted time and cut costs [7, 8]:

- Shorten preparation time of medication
- Allowing parents to room in with their children
- Revising and improved payment terms
- Shorten patient's length of stay
- Find root causes of problems
- Reduce paperwork mistakes
- Standardize worksheets
- Create poka yoke steps
- Reduce travel distance
- Increase floor space
- Reduce inventory levels

By reducing the number unneeded activities administrators and physicians improve the overall utilization of the facilities resources, cut costs for both labor and equipment use, and improved the quality of care for patients by freeing up staff and equipment. The use of 5S, Lean, and Six Sigma in healthcare has proven to show impressive results in improving efficiencies and reducing overall health care operating costs.

Section 3.2 Real-Time Location System

One new growing trend in healthcare for process improvement is the implementation of RTLS. These systems allow employees to quickly locate different assets and resources throughout the facility in real-time. Small data badges are assigned to these assets and resources that are detected by locating devices that are installed throughout the facility. Improvements in this type of technology has allows these systems to be very accurate and becoming more sought after.

RTLS is growing in popularity in the healthcare field because of opportunities it can bring. Below are a few major uses of RTLS in healthcare today [9]:

- Equipment Tracking
- Continuous Monitoring
- Patient and Staff Safety
- Patient Flow
- Infection Control

The ability to reduce unneeded activities would create higher utilization of resources, cut costs, and improve the quality of care for patients. The use of 5S, Lean, and Six Sigma in healthcare has proven to show impressive results in improving efficiencies and reducing costs, but has not been enough to make the impact needed. RTLS has the ability to show the current state of the institution and how it is performing. This allows health care facility administrators the ability to assess the situation more quickly and to make more informed decisions, which in the end, directly impact the quality of care patients receive while cutting costs.

Section 3.2.1 Overview

An RTLS uses a wide range of different technologies to perform a similar task of tracking assets and resources to help improve efficiency. These systems are performed on different tracking methods but mostly are made up of comparable components. [10]

- **Tags** – Small mobile devices that are attached to each object being tracked. Usually small enough to be carried by the user without being a burden. Can be in the form of wrist bands, simply clip on badges, or just chips. Send data to the location sensors to provide the current location of the object. Figure 1:
- **Location sensors** – Placed throughout a facility to detect the tags. Figure 1: [9]

- **Location engine** – Once a location sensor has detected a tag it sends the information to the location engine which determines the current position of the tag.
- **Middleware** – the software that resides with the pure RTLS components and the business application of creating value of the technology. Connects two applications so that can exchange data and provide the result the user wants.
- **Application** – Software that works with the middleware to perform the job the user needs. This could be showing where a tag is and what other tags have come into contact with the badge.

Figure 1: RTLS tags

An RTLS might use different technologies to track patients but are mostly made up of these main components. Along with the different technologies available, different RTLS can track the tags in the variety of ways. Based on the need for the RTLS, the precision of the tags location can change. This will allow the healthcare institution to pick the systems they need depending on the level of accuracy required. Different levels of precision for RTLS are as followed: [10]

- **Presence-based location** – System that shows the location of the tag in a general area, like a specific floor or wing of building.
- **Locating at room level** - System that shows the tag's location at the individual room level.
- **Locating at sub-room level** –level of precision of this system will show the location of the tag in a specific part of a room.

- **Locating at choke points** – System that determines the location of a tag as it passes by a predetermined point, this point can be a door, part of a wall way, or other.
- **Locating by associating** – System that shows location of tag by their proximity to other tags. Can show how far a patient or nurse is from a needed piece of equipment.

The different precision levels of RTLS vary through the health care field because no one system is right for each healthcare environment. This lets each institution choose what is best for its individual needs that will provide the greatest increase in patient care while reducing the overall operating costs.

Section 3.2.2 RTLS Benefits

In healthcare, time is of the essences, whether it is finding a piece of equipment or having to make a quick decision that could save someone's life. RTLS have a wide range of uses that would greatly benefit healthcare facilities. The first benefit is the ability to track assets throughout the facility. These assets can include the patient's beds [11] or specialty equipment like infusions pumps. Medication can also be track to help eliminate fraud and to make sure patients get the correct medication.[12] With the capability of tracking equipment, healthcare facilities can save money by minimizing the amount of equipment that is required to be purchased or rented. [13] RTLS can track and store the movement of equipment item throughout the healthcare facility. This application would be extremely useful when trying to contain infection or an outbreak. The ability to track nurses and doctors or other personnel is also an important benefit of the system. In the case of an emergency, where additional support is needed, the system can locate and dispatch the proper additional resources to the area in the facility that is in need. The system could also show how often nurses and doctors visit their patient which can lead to an increase in patient care and satisfaction. RTLS have also been used to help improve elderly fall detection which would increase responses time and prevention. [14]

One the big advantage of a RTLS is to improve the patient flow and to reduce overall wait times. A quick list of the benefits of patient tracking is [15]:

- Decrease the patient's total length of stay
- Improve utilization of personal resources, like doctors and nurses
- Reduce inventory costs
- Quicker personal information lookup times
- Receive revenue faster
- Reduce wait times
- Easily keep up with key metrics and adjust accordingly
- Increase patient care and satisfaction
- Create less stressful environment for staff
- Increase safety

RTLS have a great deal of benefits that help lower costs and increase patient care, however there are different kinds of RTLS that all do similar tasks but performs differently. The applications that they can perform can vary greatly and as a result, should be reviewed with scrutiny when deciding on a RTLS. Table 1 [16] shows the top three different kinds of systems and what different benefits they have to offer.

Table 1: Benefits of Different RTLS Technologies

Technology	Benefits
Wi-Fi	• Most Healthcare facilities already have wireless installed • Allows for any Wi-Fi enabled devices to be tracked • Devices are detectable through walls
RFID	• Can combine active, semi-active, and passive tags • Tags are usually less expensive (passive tags) • Limits interference on existing networks
Infrared (IR)	• Has high room-level precision • Signal does not penetrate walls

Each of the RTLS technology offers different benefits that make the system unique. A healthcare facility should study their existing processes and determine which technology system would best suit their needs. The benefits that each system has shouldn't be the only aspect looked at when buying a system. The downsides should also be carefully reviewed in order to compare both the overall benefits with the return on investment to avoid needless expense.

Section 3.2.3 RTLS Disadvantages

Even though RTLS have an impressive list of benefits there are some downsides. RTLS are very expensive and require infrastructure and training costs along with the purchase of the system. The different technologies used in RTLS also have their disadvantages compared to each other.

Table **2** shows some of the main disadvantages to each technology. [15, 16] From the table, the disadvantages of the systems vary with each technology and each should be considered when picking the correct system.

Table 2: Disadvantages of Different RTLS Technologies

Technology	Disadvantages
Wi-Fi	• Isn't as "plug and play" as told by vendors • Cost to keep it calibrated • Wi-Fi tags create "noise" with existing networks • Been reported to have lower location accuracy • Interference with other networks
RFID	• High infrastructure costs • Active tag's battery need replacing • Passive tags have to be passed over sensors • Passive tags need higher fixed costs
Infrared (IR)	• Must have line of sight to work • Only Accuracy to a given area

Section 3.3 Simulation Modeling

One focus of cutting cost in healthcare has been towards improving the process times of procedures. One of the most frequent complaints from patients relates to the ever increasing wait time that they have to endure before seeing the doctor or specialist or in the total time required of them to undergo a scheduled procedure. A possible solution to this would be to use simulation modeling of the process to increase the efficiencies. Most simulation models study and optimize the patient flow to try to minimize wait times at different prep or procedural station. Patient wait times not only are a non-value added process but patients most often perceive it as lower quality of care.[4] By collecting patient flow data, simulation can optimize the patient routes and also the amount of resources required to treat the patients.

Simulation modeling has the potential to play a part in training and quality of service as well. By using a simulation model of the facility, employees can help train new hires by showing them situations that could really happen to that facility. This application would allow trainers to replicate real life situations and to teach “What-If” scenarios regarding how to change an outcome with different approaches to solving the given problem. [17] Simulation modeling has also been used to optimize nurse-patient assignments to combat the growing lack of nurses. By 2015, there is expected to be a 20% shortage of nurses, so the efficiency of the nursing staff will become a bigger priority over time. The capability of optimizing nurse scheduling, rescheduling, and shift assignments will help reduce cost and put the users of this method ahead of the competition. [18] Monte Carlo simulation techniques have also been used in healthcare for scheduling analysis, assessing risks in infrastructural projects, and predicting the contribution of biotechnology industry. [19] The application of simulation modeling in healthcare processes also has the ability to predict future outcomes. With given data, a simulation model can run a future outcome of a predetermined scenario to give managers more data driven guidelines for decisions. The use of plan views models can also provide the health care facility administrator with insightful data that they can utilize to alleviate underutilized resources or to identify where there are insufficient resources as well.

A simulation model does provide a great tool to improve healthcare efficiencies but it does have its drawbacks. In healthcare, simulations often lack enough data for the model and it can only produce approximate results. This makes verification and validation of models untrustworthy to some users. Because some users don't believe simulation can capture the true flow and feel of a healthcare environment people are very hesitant to accept its potential benefits. [17] The data needed for all the inputs and parameters are not readily available or very time consuming to obtain. Most healthcare environments have variable patient tracks due to the large number of different reasons patients are visiting. Due to this complexity of the healthcare industry, the collection of enough data could take a long amount of time to acquire. To stay current, the healthcare industry consistently has to update its technology and procedures, which in turn, requires them to continually update the way in which patients are processed. Each time the process drastically changes, the data collection process would have to change as well. This time consuming process of collecting and recording data for healthcare processes creates a challenge for implementing continuous improvement.

Chapter 4 Methodology and Framework – Combining RTLS and Simulation

There are a wide variety of benefits with simulation modeling, RTLS, or Lean manufacturing. Any of these can result in cost reductions through increased efficiency of both the healthcare facility and its needed resources. The use of any single system has not been enough to lower the cost of healthcare enough. Healthcare costs are still too high and there are still inefficiencies within the system. The problem is that each is missing an important part, whether it's having real time data for a simulation model or the system can only show past and current metrics and can't predict future outcomes. The ability to combine all these individual methods into a uniformed system could have a major impact in the healthcare industry to significantly reduce cost and increase the quality of care. A system that combined all four of the main functions would have the greatest impact on efficiencies. The four functions will work together to harness key patient data to the current available resources that are needed to expedite the required treatment. This adaptation would provide physicians with key information that they could use to make more data driven decisions.

Section 4.1 Real-time data acquisition

Using an RTLS the system would collect real time data of the facility. Real-time data is vital in healthcare because every second counts and can the difference between life and death in an emergency situation. The ability to make good choices quickly can mean saving someone's life. Collecting current data is important because it will allow managers to see how the system is performing when managers need to make decisions. Without the current data, the other functions of system will not display data that will help in current dilemmas. The system will have the capabilities to show the current location of all the assets and personal resources throughout the facility as well as the storing and the retrieval of all the historical data.

Section 4.2 Optimization

Managers always want to know what the best possible circumstance they can have. With inputs from the RTLS the system can optimize key operations. When a physician needs to make data driven decisions, he can run the built in optimization program that will take the current data and produce the best possible outcome based on the present environment. This would result in improved staffing optimization by eliminating unneeded staff or ensure that the correct staffing levels have been scheduled. This could also be used to increase patient flow through the facility and allowing for more patients to be seen. The optimization could be developed to improve different given metrics that in turn would create the greatest improvements for each independent facility.

Section 4.3 Predictive Modeling

Besides having the ability to provide optimization, the system will use data collected by the RTLS to formulate trends and make predictions. Managers can use these predictions to see how the facility will operate if the current state of the facility continues. By knowing how the institution should perform, it allows the facility managers to make decisions quicker and with more confidence. Using the forecasting ability of the system a "What-If" function can be used to change variables to see how outcome might change. This would allow the managers to see how their decisions could impact the future and choose better outcomes.

Section 4.4 Intelligent Information Processing and Data Visualization

The ability to have all of this productive information is useless without a simple way to display it. The implementation of a user-friendly dashboard can provide all the information that managers and staff need to make their job easier and more productive. Different metrics will be shown to help the staff in their daily decisions such as the number and type of doctors available to see patients, the average patient total length of stay, and the up to the minute utilization of each resource. Each work station would have its own customizable screen that shows the information needed for help that particular position or station. Figure 2 shows a dashboard example for the overview of a clinic and Figure 3 shows an example of a front desk personal's dashboard. The dashboard will be user-friendly and allow the same information to be displayed in several different ways. This allows a user to pick what information they want to see and how the information is displayed. The different display options can vary from numeric tabular displays or a wide range of graphical charts. This will allow the information to be processed quickly and reduce decision times for staff. The dashboard will also provide a way to see the facility from a plan view to get a better understanding of the current condition of the entire facility, facility floor, or working section. This in-depth knowledge would allow facility administrators the ability to shift and to mobilize additional resources to areas in need which would reduce cost and increase quality of care.

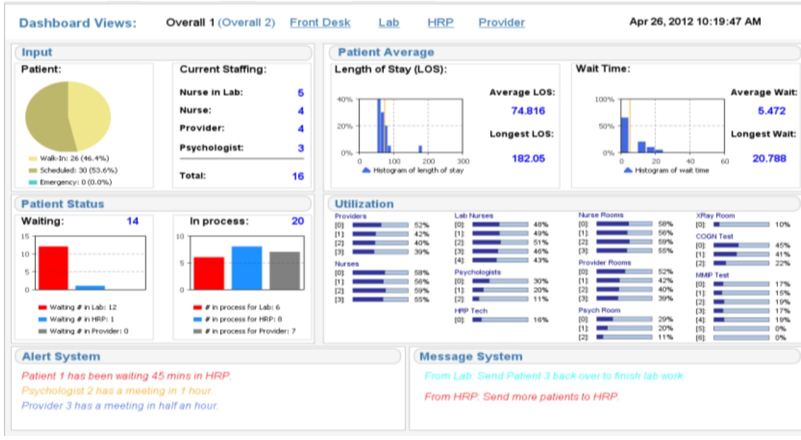


Figure 2: Overview Dashboard

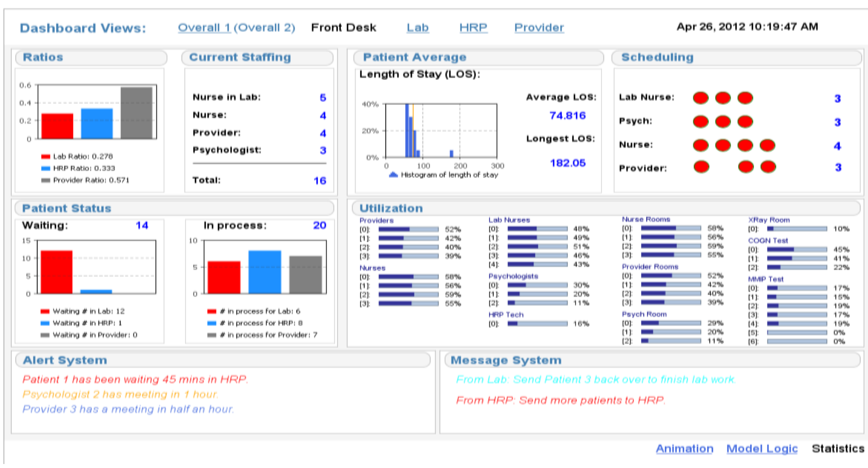


Figure 3: Front Desk Dashboard

Chapter 5 Case Study

Section 5.1 Background

The study was done at the onsite clinic at a disclosed company code named C-18. The C-18 onsite Clinic (COC) is where all C-18 employees can take medical tests and procedures. The clinic was having problems with long wait times that in turn would keep employees tied up at the clinic instead of being productive at their job. Employees who visited the clinic were paid for their time because most tests were required before they could perform their job. COC normally treats between 90 and 150 employees Monday through Thursday from 6:00 am to 5:30 pm.

The clinic is composed of three main sections that patients can visit. The first is the provider section, where patients can see a nurse and/or medical doctor. Tests and checkups ranges from normal medical clinic visits to C-18 necessary tests. The second section is called HRP, and is the psychology part of the clinic. In this section patients can talk to a psychologist for personal reasons and testing to see if they are mentally able to perform their job. The third section is the lab where patients get tested to check their personal health. Tests such as blood work, urine, hearing, and vision make up the standard by which employee health is assessed. The different personnel needed at COC are as followed:

- Providers: – Evaluate and treat patients' physical health;
- Psychologists: – Evaluate and treat patients' mental and emotional health;
- Nurses (RNs): – Perform a variety of key tasks
- Lab Technicians: – Perform lab tests and analyze the results
- HRP Coordinator: – Controls the flow of patients through HRP
- Health Information Manager: – Controls scheduling and flow throughout the clinic
- Psychologist Trainees: – Help in the evaluation of patients
- Others resources like computers are used to take tests that do not require any supervision.

Section 5.2 Current Problems

The clinic is currently facing a variety of problems that is hindering its performance. The problems that are identified are as follows:

1.) The total patient time-in-system is excessive and is preventing the patients from returning to their assigned task in a reasonable time frame.
2.) Long wait times
3.) Lack of communication between the different testing/review sections creates confusion and keeps patients from value-added activities.
4.) Managerial decisions are based on experience and instincts instead of real time data.
5.) Staff utilization is sometimes mismatch, so that one section has free time while another is back upped with patients.

The combination of these problems causes the clinic to run less efficiently and requires the patients to stay in the system for extended time frames. The majority of the problems stem from each section of the clinic only looking at their particular section rather than integrating all the different sections as a whole. This narrow vision creates bottlenecks in each of the process stations that could've been prevented. Because the longer each patient stays in the clinic the longer they are away from their primary job a responsibility which creates additional burdens and cost for the company as they react to their workers being away from their assigned task.

Section 5.2.1 Patient Flow

When a patient arrives for a physical they normally follow a set path depending on what procedure for which they are scheduled. The flow of patients who are there for a physical can be seen in

Figure **4**. This flow chart depicts how a patient may be processed through the clinic, the processes that may be scheduled, and the respective sections that can be utilized. The physical was the only flow chart described because it is the longest patient category and causes the most bottlenecks. As the chart shows, the process has many variables and several different ways that a patient can be processed through the clinic. The use of an RTLS and simulation modeling system could be used to help improve patient flow and reduce the total time a patient spends in the clinic.

This flow chart, however, is very generic and doesn't cover the full dynamic environment of the clinic. Depending on the reason a patient arrives at the clinic, their personal path may differ from other patients. This creates a problem when trying to standardize patient flow. All the different path variations make it hard for the staff to keep up with where every patient needs to go to finish the visit quickly. A process map was created to keep up with all the different routes a patient would probability take. This is broken down into each of the primary sections along with a clinic overview and emergency care area. It also shows how patients travel through each section and the different flows generated between each section. Some sections, like the provider section, are somewhat standard compared to HRP section. The overall path of the clinic is where miscommunication happens and where long wait times begin. Staff members in each section do a good job trying to create efficient flow within their section but they do not have any insight to the other sections. Once a patient is finished with a section they might be sent to another section that is already full when they could have been sent elsewhere with shorter wait time. This is where an RTLS could really have a positive impact. A description and the flow of each in the process map can be found in Appendix A.

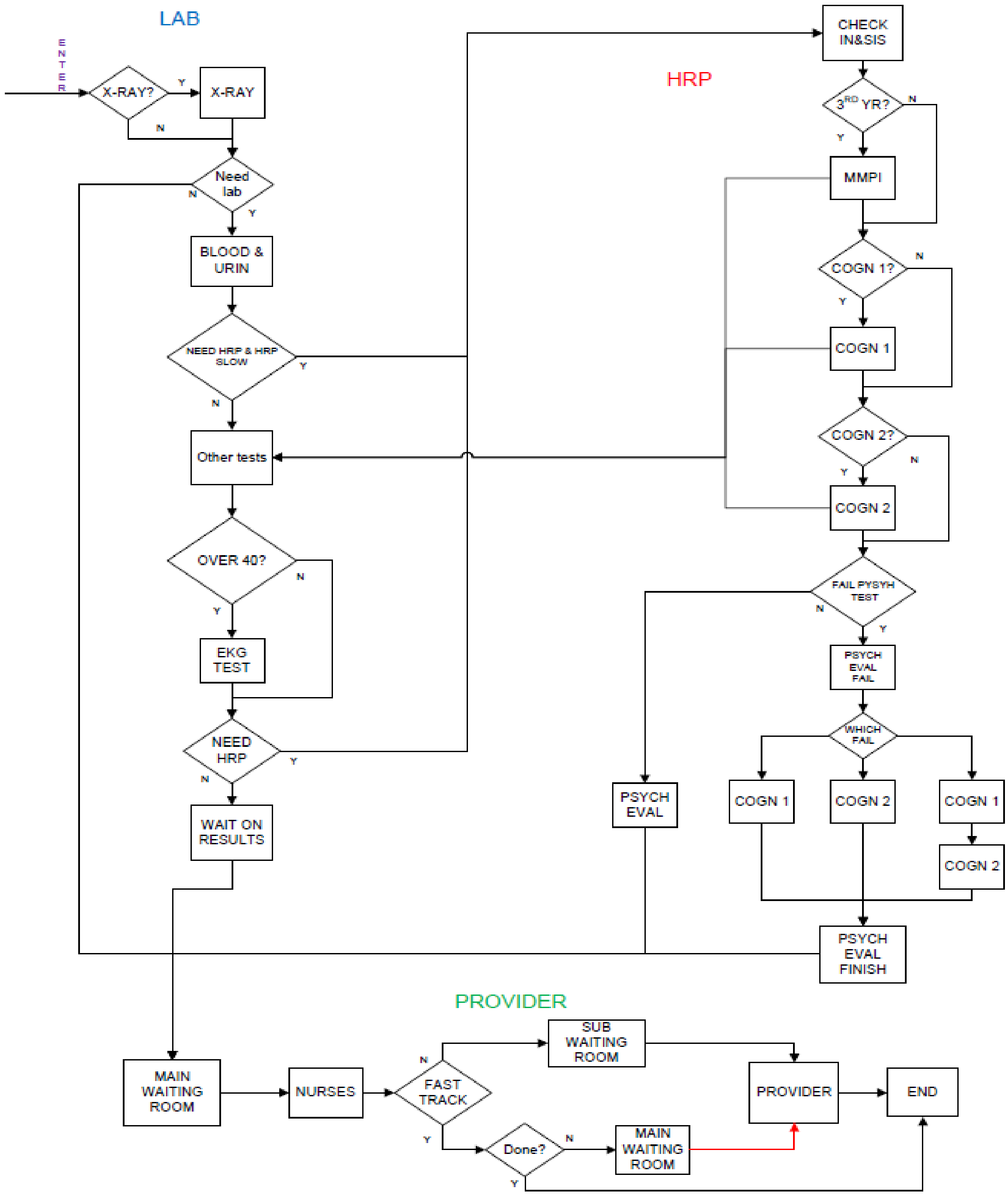


Figure 4: COC process flow of physicals

Section 5.2.2 Patient Categories and Flow

When a patient enters the clinic they are put into a category based on what procedures for which they have been schedule. Most patients will fit into a set of eleven categories with each one encompassing a wide range of tests and procedures. The eleven categories are as follows:

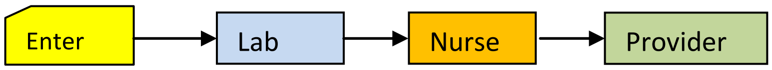
- Physicals
  - HRP Physicals – Patients are evaluated for their mental and emotional fitness to perform their jobs
  - NON-HRP Physicals – Patients are evaluated for their physical fitness to perform their jobs
- Occupational Injury and Illness
- Walk-ins
- Physical Therapy
- Medication and Condition Reporting/Monitoring
- Psychologist Visit
- Medical Evaluation
- Return to Work
- Emergency Visit
- X-Ray Evaluation
- Miscellaneous Medical Activities

Each of the patient categories has different assigned routes through the clinic that the employees will take to complete their scheduled procedures. These routes are not absolute and can be changed according to how conditions within the clinic dictate. The only steadfast requirement is that all the steps within a procedure must. The basic category flow is as follows:

Physicals

- HRP Physical

- NON-HRP Physical

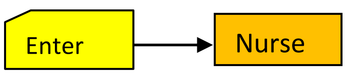


- Continuation of Physical

Occupational Injury or Illness

Walk-ins

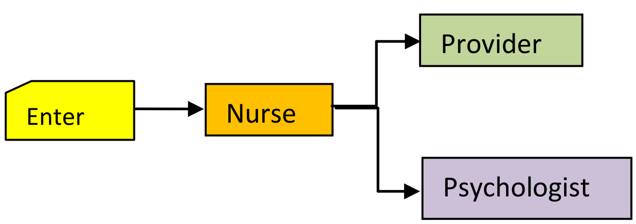
Allergy Shots



Medication and Condition Reporting/Monitoring

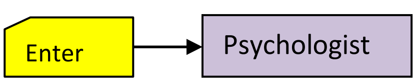
(First time only; patients proceed to Physical Therapy afterwards)

Medical Evaluations



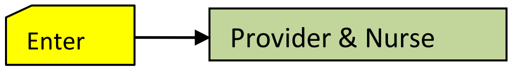
(Patient may see both)

Psychologist Visit



Return to Work

Emergency



Section 5.2.3 Data Analysis

The patient's categories and flow information was used to create the patient path ways for the simulation model, but just knowing the flow is not enough. Other information is needed for the model to more accurately represent reality. To obtain the information needed, the COC's database was used to extract a full year of data that would be beneficial for the model. The database shows all the information regarding patient activities within the clinic.

The first bit of data extracted was basic information about the patient's entry. The model needs to know the breakdown of the number of patients that enter the clinic. The graphical representation of the information pulled from the database, about the number of patients, can be seen in Figure 5 and Figure 6. Based from the data and chart the average number of patients was 117 a day. The breakdown of the day of the week influenced the number of patients is shown in Figure 6**Error! Reference source not found.**. Besides the number of patients, the distribution of the times they arrived is also needed for the model. An arrival schedule was decided to be the best fit since it would be more precise than a statistical distribution. The arrival time of each patient was pulled from and data and the graphical breakdown can been seen in Figure 7. This chart shows the percentage breakdown of the arrival times for each weekday. With the daily average number of patients, weekday breakdown of patients, and the arrival time breakdown data, the schedule of patient arrivals can be completed. The final patient arrival schedule can be seen in Table **3**. The table shows how many patients will arrive at each time block for each day of the week. This schedule will be used as the entry module for the simulation model to represent how the patients arrive at COC.

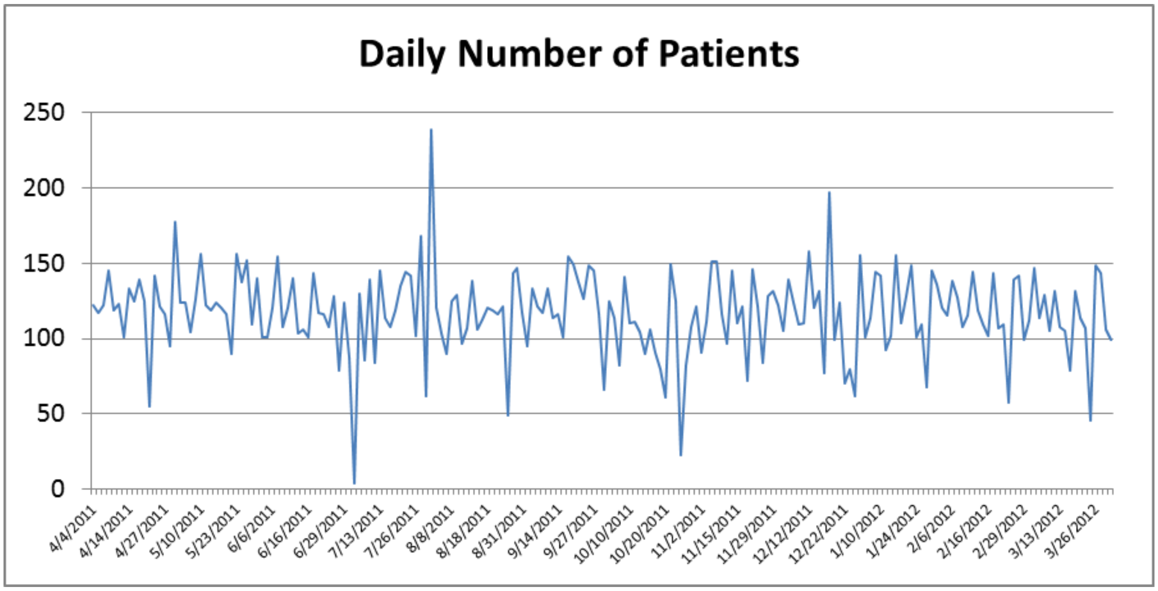


Figure 5: Number of patients a day

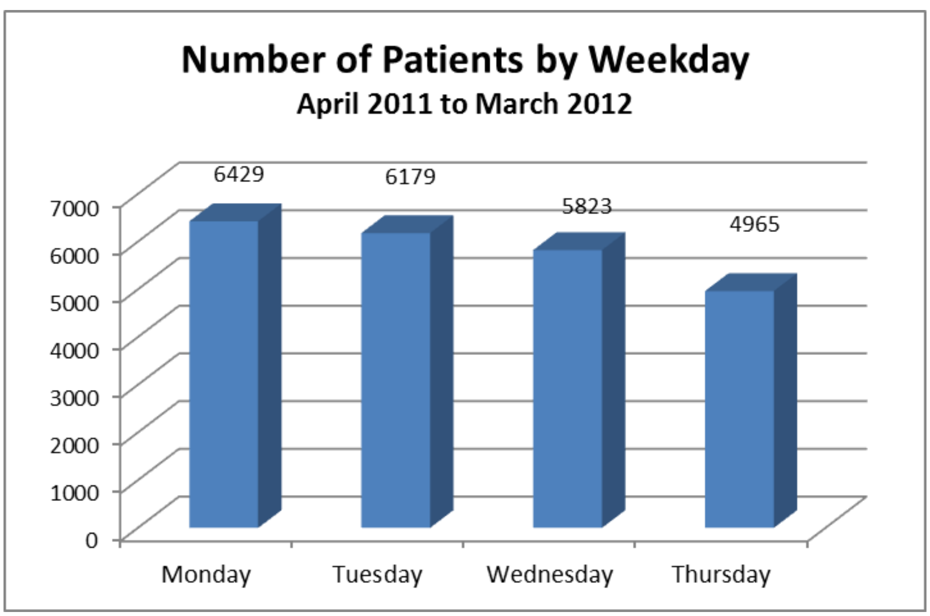


Figure 6: Number of patients by weekday

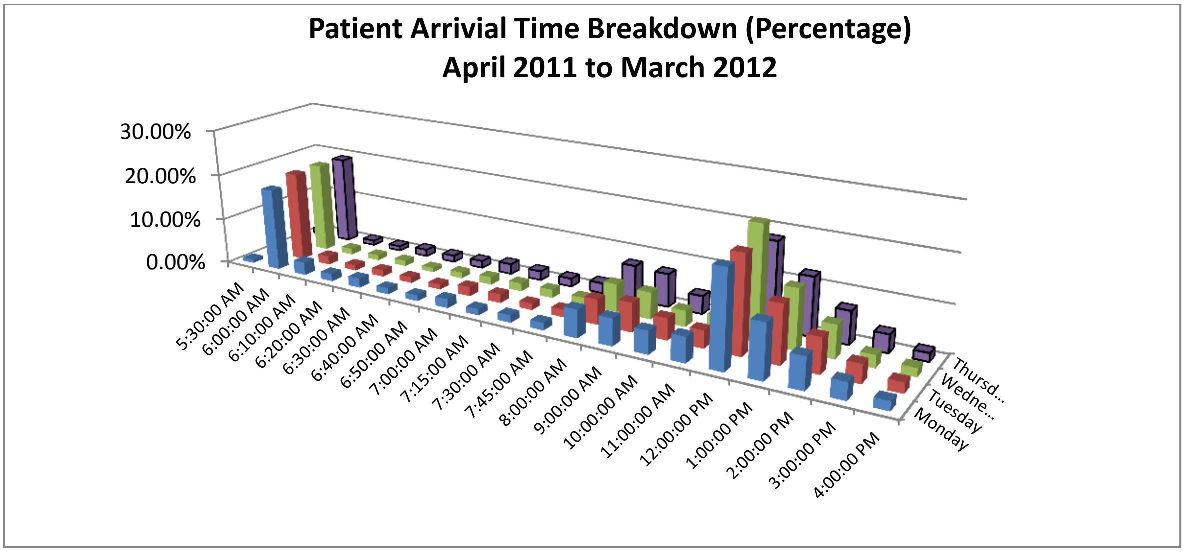


Figure 7: Percentage Breakdown the patient arrival times

Table 3: Patient arrive schedule

Weekday / Time	Monday	Tuesday	Wednesday	Thursday
5:30:00 AM	1	1	1	1
6:00:00 AM	23	24	23	19
6:10:00 AM	4	2	2	1
6:20:00 AM	2	1	1	1
6:30:00 AM	3	2	1	1
6:40:00 AM	2	2	1	1
6:50:00 AM	2	1	2	2
7:00:00 AM	3	2	2	2
7:15:00 AM	2	2	2	2
7:30:00 AM	2	2	2	2
7:45:00 AM	2	2	2	2
8:00:00 AM	8	7	7	7
9:00:00 AM	7	8	7	7
10:00:00 AM	6	6	4	4
11:00:00 AM	7	5	4	4
12:00:00 PM	26	25	28	18
1:00:00 PM	15	15	15	12
2:00:00 PM	9	9	8	7
3:00:00 PM	5	5	3	4
4:00:00 PM	2	3	2	2

Along with the entry schedule, the database can also provide information about the patient category breakdown. By knowing this breakdown, the flow can then be assigned to its respective category. With this information the criteria for the patients' flow can be more realistic. The breakdown of the all the different reasons for arriving at the clinic can be shown in Figure 8. Because there are so many reasons a patient can enter the clinic, this data would be too overwhelming and needs to be grouped into smaller sets. This can be seen in Figure 8, Figure 9, and Figure 10. Figure 9 shows the breakdown the activities in the major activities and classifies all the minor processes into a single category to make it easier to process. Figure 10 displays the category breakdowns in their most general form. All patient activity breakdowns were used to create the criteria for how a patient flows throughout the clinic. This information is used for the decision model criteria: patients that see HRP, take COG tests, and other judgment decisions.

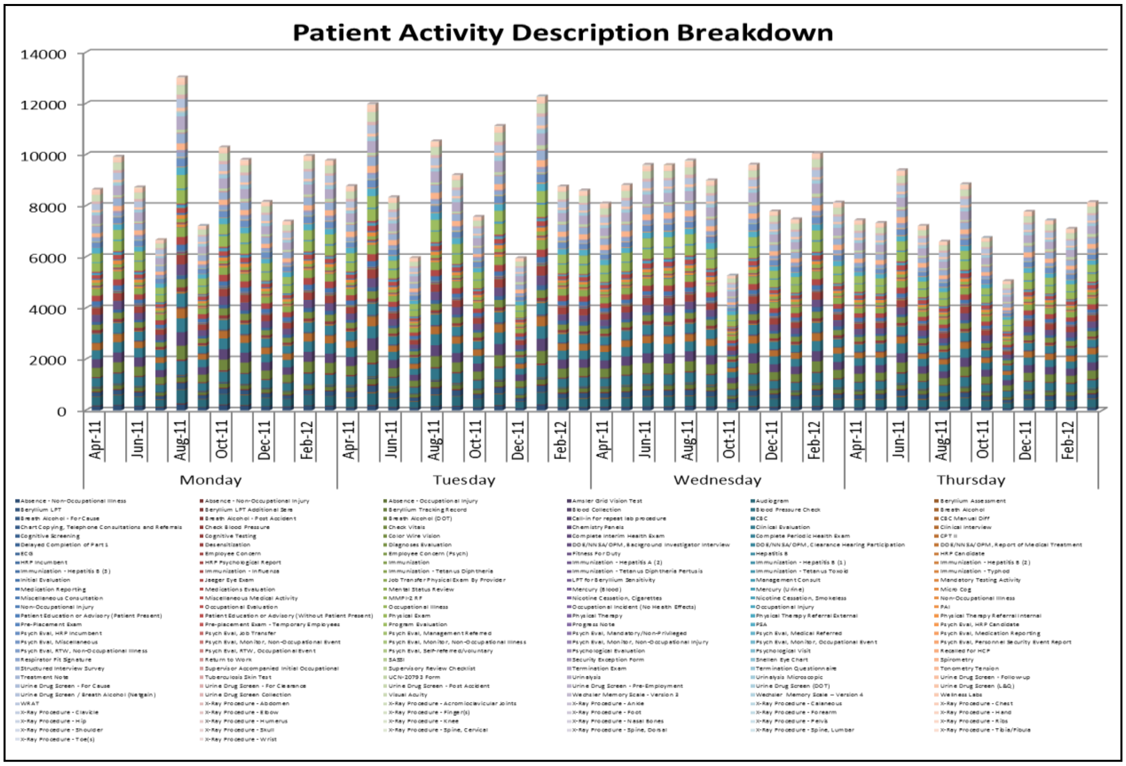


Figure 8: Breakdown all patient activities

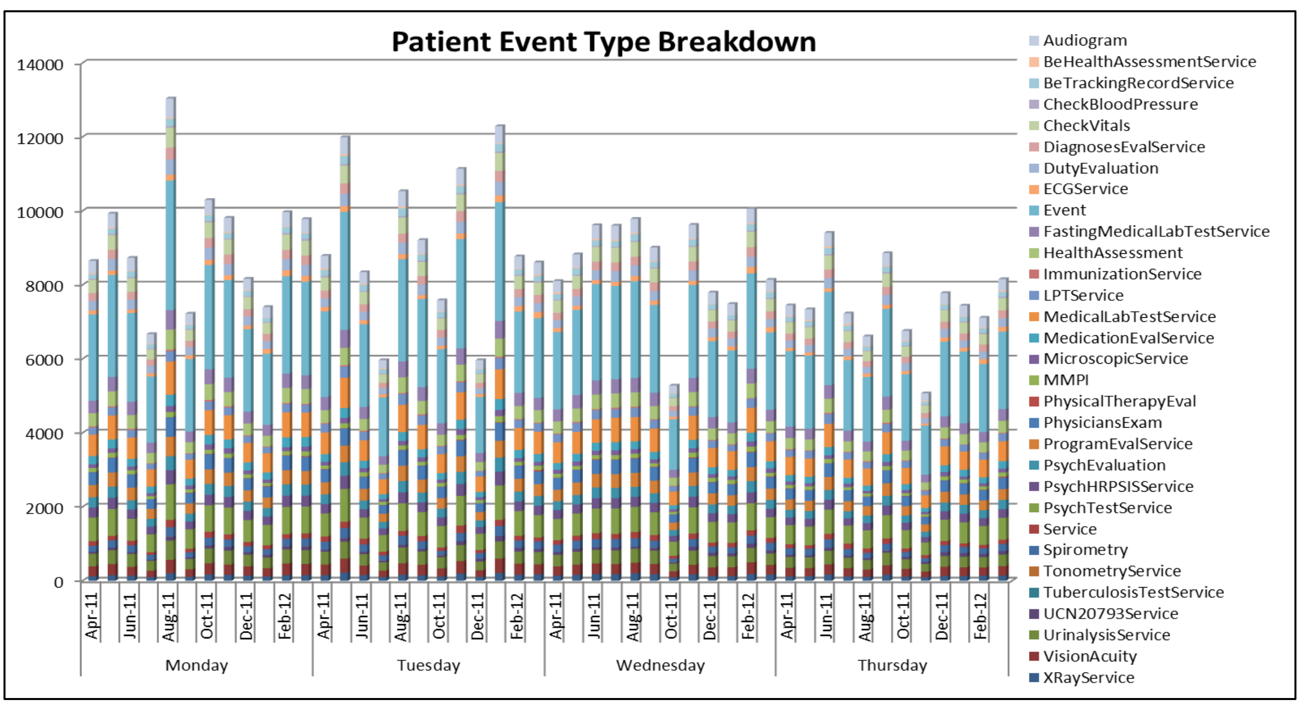


Figure 9: Patent breakdown with medium amount of category sets

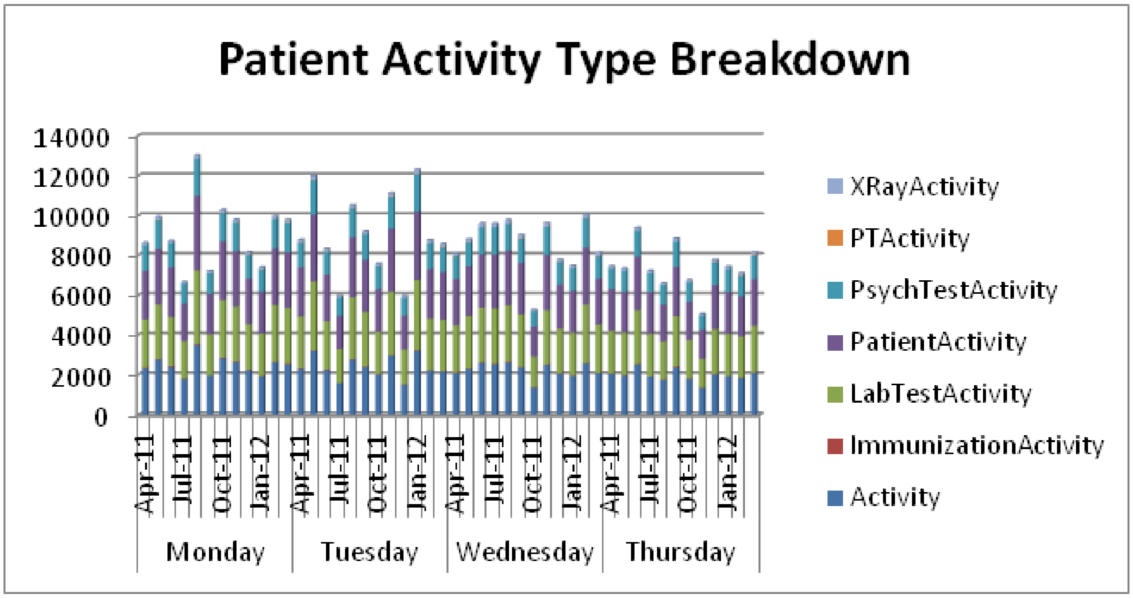


Figure 10: Basic patient category breakdown

To check how the accuracy of the model, total patient time in system numbers were pulled to make sure the model represents reality. Figure 11 represents percent breakdown of the length of time each patient stays at the clinic. The results from the model can then be compared to the numbers from Figure 11. If these numbers do not match it will be red flag for a problem with the model. If they do not match, it will be a red flag indicating a problem within the model. Other outputs will also be looked at to make sure the model is accurate and useful.

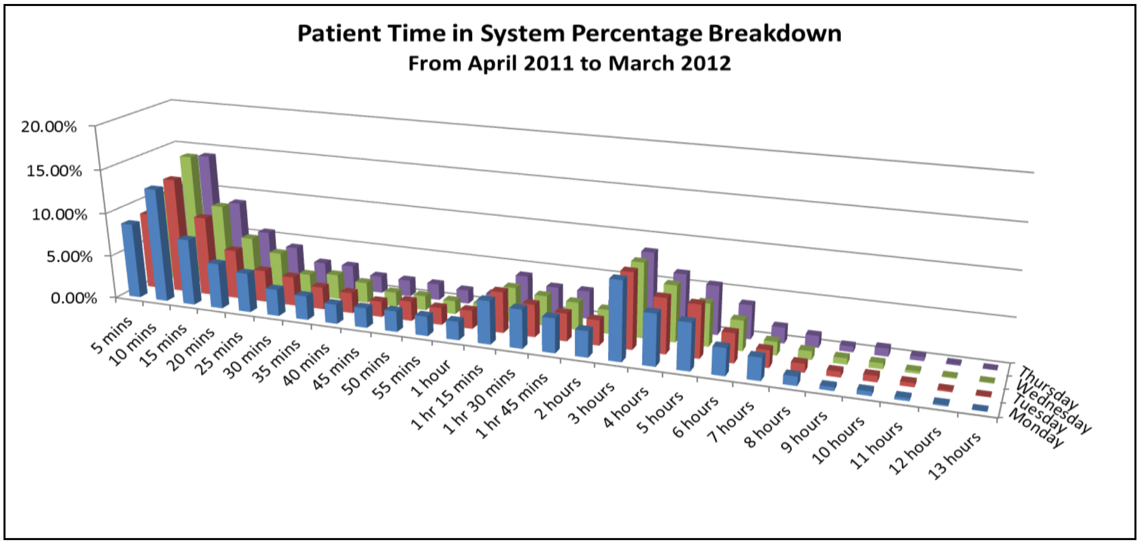


Figure 11: Patient time in system breakdown

With all real data from the database, the model will be more useful to show how the clinic operates. The database helps show key information that is vital to the success of the model. The data pulled, along with patient category flow, helped give us a majority of the information needed for the model. The simulation model now has enough information for the entry module, the design and flow of different processes, and the criteria for the flow of different patient category and activities. This data is not enough; therefore, the model still needs additional information like the distribution times for each process, different criteria of flow in the clinic, and rules for the clinic that the database cannot provide. Additional information will have to be collected through interviews or studies. Once the base model is complete it will pull all the information it needs from the RTLS to continually update itself to make sure it represents the current state of the clinic.

Section 5.3 Math Model Example

The case study, which used the math model in section 2.1, illustrates how the model would improve their existing scheduling system. It will then lay out a schedule for different patient categories during a single work week (Monday – Thursday). The categories were selected from the provider section of the clinic and the overall demand usage was pulled from a single week from real data extracted from their database. The costs were based on estimated amounts for the providers, and revenues were estimated based on the importance and treatment times. Other sets and parameters were also estimated based on known and available data. The σ_i parameter and Equation 4 was not needed since the constraint was unnecessary. The sets and parameters are shown in Table 4: The μ_{it} are shown in

Table **5**.

Table 4: Math Model example sets and parameter

Sets / i	Demand (Q_i)	Time per Treatment (Z_i)	Revenue (R_i)	w_i	ρ_i
X-Ray Evaluation	9	25	25	0.05	0.4
Occupational Illness	1	22	30	0.07	1
Occupational Injury	6	20	15	0.09	1
Non-Occupational Injury	7	20	25	0.02	1
Medication Reporting	17	18	10	0.05	1
Physical Non-HRP	38	35	20	0.8	0.9
Physical Therapy	10	15	20	0.06	0.5
Physical HRP	70	60	60	0.07	0.4
Return to Work	29	35	30	0.02	0.8
Non-Occupational Illness	5	25	20	0.02	0.6
Miscellaneous Medical Activity	4	25	15	0	0.6

Table 5: Required number of patient percentage for each category

	Monday	Tuesday	Wednesday	Thursday
X-Ray Evaluation				
Occupational Illness				
Occupational Injury				
Non-Occupational Injury				
Medication Reporting	30%	30%		
Physical Non-HRP	40%	40%		
Physical Therapy				
Physical HRP				
Return to Work				
Non-Occupational Illness				
Miscellaneous Medical Activity				

The remanding sets and indexes are as followed:

Time slots

1. Monday
2. Tuesday
3. Wednesday
4. Thursday

Z_{it} *All patients times are the same in all time slots

T – 7 hours*60 minutes*four employees = 1,680.00 minutes

The model came to a solution and the results are shown in

Table **7**: Amount of time used in each time slot

and

.

Table **7**: Amount of time used in each time slot

shows the number of patients in each category that were scheduled to each time slot (day of the week). The total time taken in each time slot is shown in

. The model found the optimal schedule that maximized the profit at $ 3,456.20, which indicates that it works and will find solutions to other similar problems. Adjustments can be made to fit the schedule in different time frames such as months, weeks, or hours.

Even though the model provides a depletion of the process flows, its ability to depict the processes is directly proportionate to the level of detail that is fed into the model. The more accurate the data that is initially put into the model, the more accurate the model and results will be. In the referenced example, most of the sets and parameters were intentional estimated with missing or misleading data. With this type of data set the model results indicate that the level of detail in the initial data is key to an accurate model depiction. The model does prove that with accurate sets and parameters it can find a solution.

Even if the model had accurate inputs it still wouldn't be enough to overcome the problems at the COC. It only solves for appearances in the specified time slots but not any flow throughout a facility. This limits usefulness and embellishes the need to track the patients flow to increase the efficiency of the clinic and lower the total time in system.

Table 6: Scheduling results

Category i\ Time slot	Monday	Tuesday	Wednesday	Thursday	Total seen
X-Ray Evaluation	9	0	0	0	9
Occupational Illness	0	0	0	1	1
Occupational Injury	6	0	0	0	6
Non-Occupational Injury	0	0	0	7	7
Medication Reporting	0	16	0	1	17
Physical Non-HRP	0	38	0	0	38
Physical Therapy	10	0	0	0	10
Physical HRP	20	21	28	1	70
Return to Work	0	0	0	29	29
Non-Occupational Illness	1	0	0	4	5
Miscellaneous Medical Activity	0	0	0	4	4

Table 7: Amount of time used in each time slot

Monday	Tuesday	Wednesday	Thursday
1678.69	1679.13	1625.12	1436.69

Section 5.4 Simulation Model

A simulation model will run in conjunction with the RTLS to show how the clinic has been performing and how any changes will affect its productivity. The simulation model will be used to display how the clinic is operating and optimize different aspects of the clinic. The program used, AnyLogic, was selected because it was based off Java and could run on any computer without additional programming software support. The program also offered the ability for the optimization and "What-If" functions needed for the combined system. Data gathered from the RTLS would feed into the model so it would always provide current data. The model would also have the ability to show the optimal number of staff members for each section based on the current performance of the clinic and would show how the clinic would perform if certain changes occurred. For example if a doctor had to leave the clinic, the model could show how that absence would affect the future performance of the clinic.

Initial Model

Using the data collected from the database, flowcharts of the different patient categories, and resource processing times from surveying the staff, an initial simulation model was built to show a general representation of the clinic. Additional rules and probabilities were also collected to make the model run like the clinic. Some rules and patient flow alternatives were left out because the occurrence was rare and would only happen a few times a month. The reason these rare occurrences were left out was so the model would represent a normal day. If these were left in, it could make every day have some kind of occurrence that would change the outcome of the clinic.

Because there were so many different patient flow path possibilities, the model had to separate modules and flow for each patient category. As shown in Figure 13, each category is like its own sub model. It was made this way so it would easier to change, update, and view the model. All processes in each sub-model are connected by the same resource pool. This allows it to work like a clinic and create queues for multiple patients' categories as they arrive to the resource. The model also contains some assumptions, for example, all resources work the entire 12 hour shift with no breaks.   Other assumptions are that paths given are the only options and that no rare occurrences will happen during a shift, making the model a little less creditable. Some patient categories, like allergy shots and physical therapy, were left out because they work separately from the rest of the clinic and they do not impact the overall performance. These assumptions are understood, but the model would still be useful while including them. They would not impact the model since some data was estimated, so the model would not fully represent reality. Because the simulation model will eventuality use the data collected from the

RTLS, this initial model will work to visually represent how the clinic generally operates. It will also test different aspects of the combined system like the dashboard and "What-If" analysis.

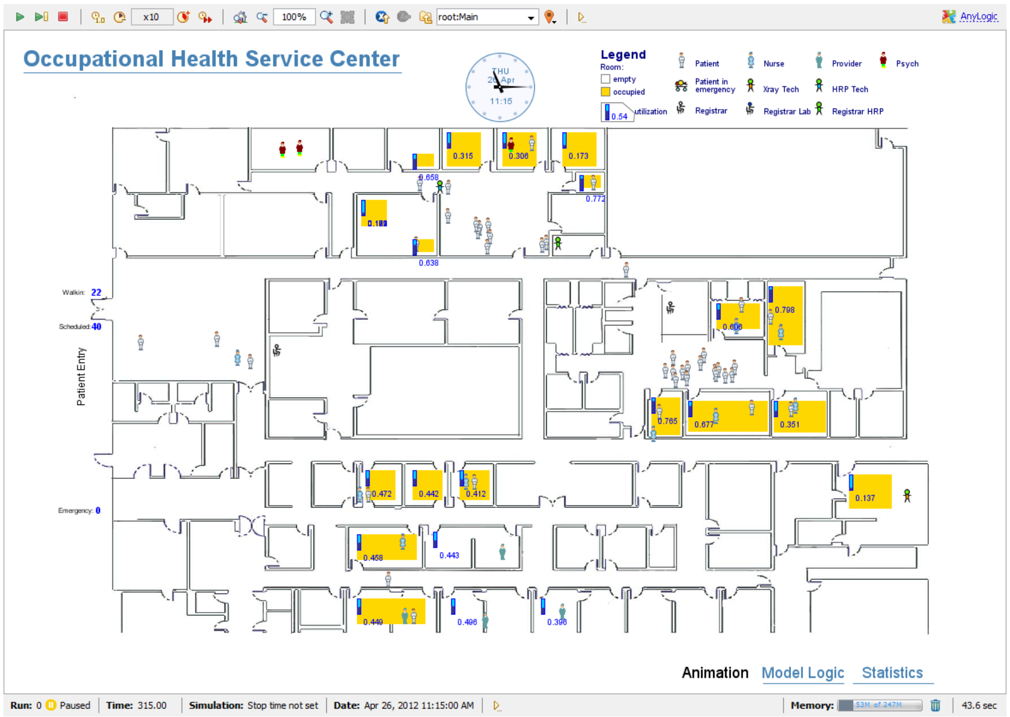


Figure 12: Simulation Overview

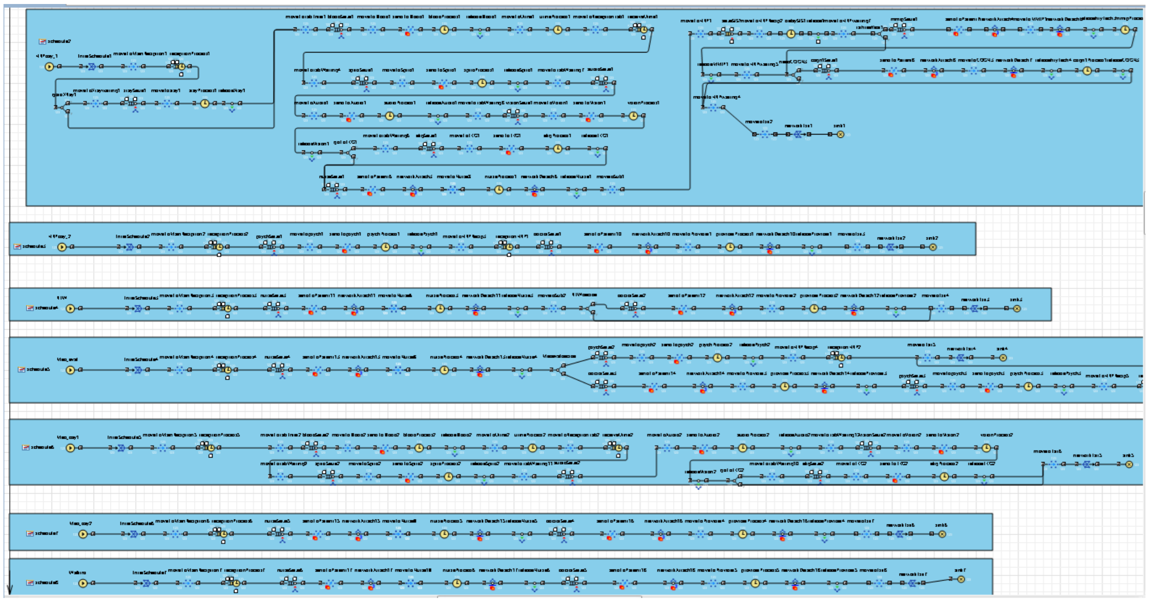


Figure 13: Simulation Model

The model was run for a day based on numbers gathered from the database. The average patient wait time and average wait time is shown in Table 8. The average patient total time in system, longest total patient time in system, average patient wait time, and longest patient wait times were used to display the results since they are the metric with which COC measures their performance. The results are close to the actually performance of the clinic. It slightly varies because of the assumptions and imprecise data. Other results can be shown like total time and wait time in each section or at each process. The numbers from the model are close enough to reality to make a conclusion. The long times in system and wait times are because the clinic schedules the majority of the patients during the morning at 6:00 around noon instead of spreading the load throughout the day.

Table 8 Simulation model results

Average Time in System	134.3 minutes
Longest time in System	616.65 minutes
Average Wait time	53.3 minutes
Longest patient wait time	309.9 minutes

In addition to just seeing possible results, the model will be able to optimize certain variables to show the best alternatives for the clinic. The simulation could optimize number of resources and other variables the clinic can control. This feature, while collecting inputs from the RTLS, will make a huge impact on any healthcare system because it not only shows optimizations for the clinic as a whole, but on a day to day level as well. It can show when the best time to make reeducation in resources throughout the day to eliminate unneeded low utilization.

Section 5.5 RTLS System

The RTLS used for COC will track all the patients and resources and collect information such as their location, time in waiting, different process times, and other important information. It will work with the simulation model to help improve flow and feed data into the model. The information collected from the RTLS will also be displayed for the staff to see how the clinic is performing. The accuracy and reliability of the system is key to the combined system because without correct information the simulation will give wrong results and managers will make hurtful decisions. Two different RTLS products, AeroScout and Versus, were looked at when choosing the right system for the COC based on their different benefits. These different products also have additional tools that will be useful for the clinic to help throughput and patient satisfaction.

AeroScout

This system will incorporate an RTLS that will be used to track every patient visiting the clinic. The ability to track the patients will help improve patient flow by showing staff where the patients are and be able to tell where they need to go. It will also show them how the other sections are doing and if they should send a patient to a less occupied section first. Along with tracking patient, the RTLS will track all staff members. This will allow other staff members to easily locate additional help if it is needed, and would allow the system to identify when a patient is with a staff member or is undergoing a procedure or just waiting in a waiting room.

Different technologies were reviewed for use in the clinic but one company was finally selected. The RTLS picked for the clinic was called AeroScout. An overview of AeroScout's operating platform can be found in Figure 14 and Figure 15. The advantages identified for choosing AeroScout are as follows: [20]

- Wi-Fi based Technology
- Does not require sensors in every room
- Software can be incorporated into the combined system
- Good track record in healthcare environments
- Long battery life for tags
- User friendly software for COC staff

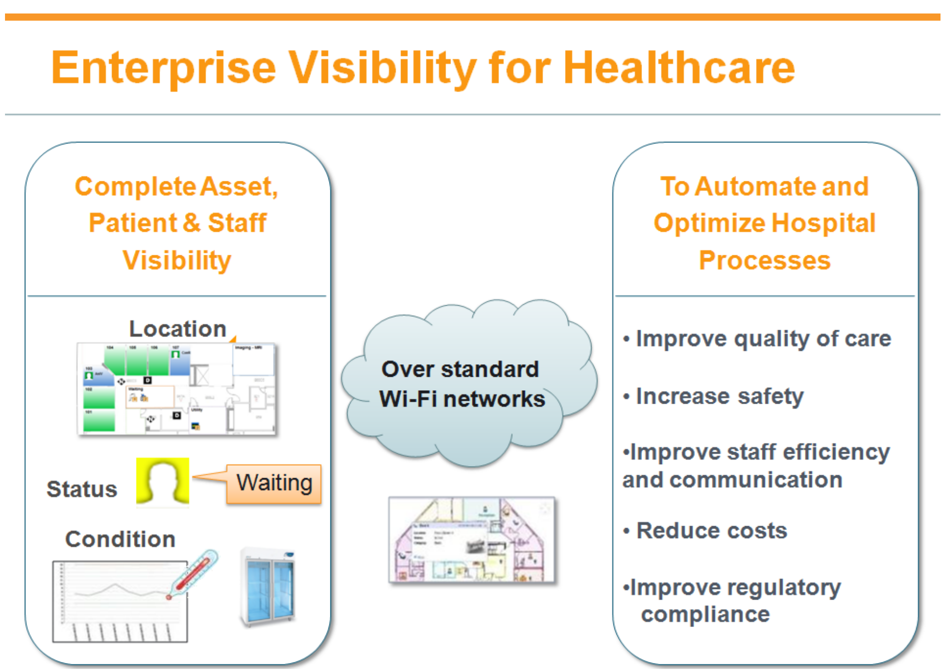


Figure 14: AeroScout overview

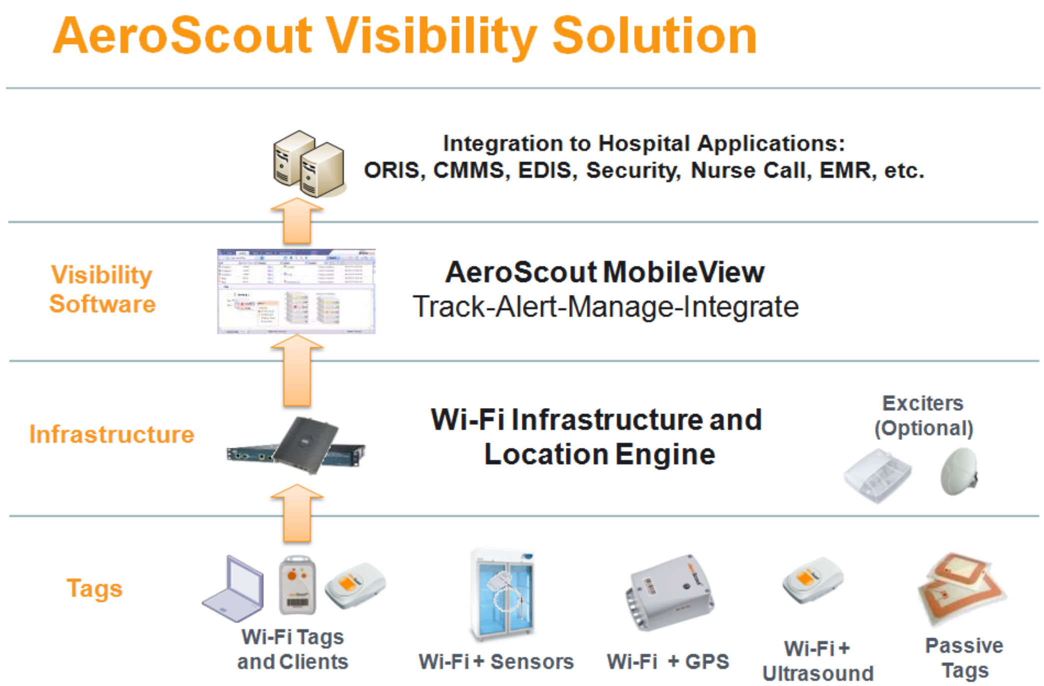


Figure 15: AeroScout components

Versus

The study also tested another RTLS called Versus. This system was tested in an off-site location so it would not disturb the staff or get them used to it. Versus used infrared technology that showed a lot of benefits and location accuracy. The system was extremely user friendly and came with additional features like room activity, contamination, badge by hour, and time tighter by zone. [21] These feature showed the system's ability to track badges and combine information from other badges to provide additional data. A view of Versus' tools are shown in Figure 16, Figure 17, and Figure 18. Even though Versus had key benefits the overall downfall was that it had to have a sensor in every room and was not very cost efficient compared to other systems. The infrared technology also required line of sight to work and if the patient covered it up with their arm or shirt it would not work properly.

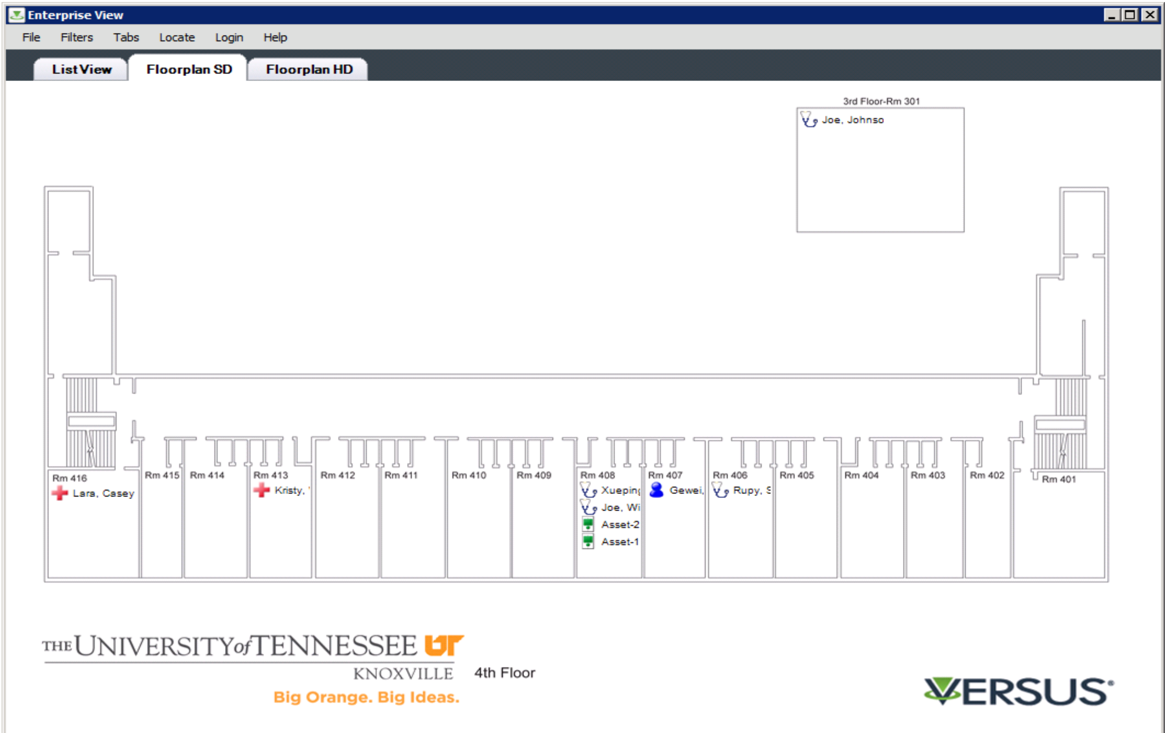


Figure 16: Versus tracking map

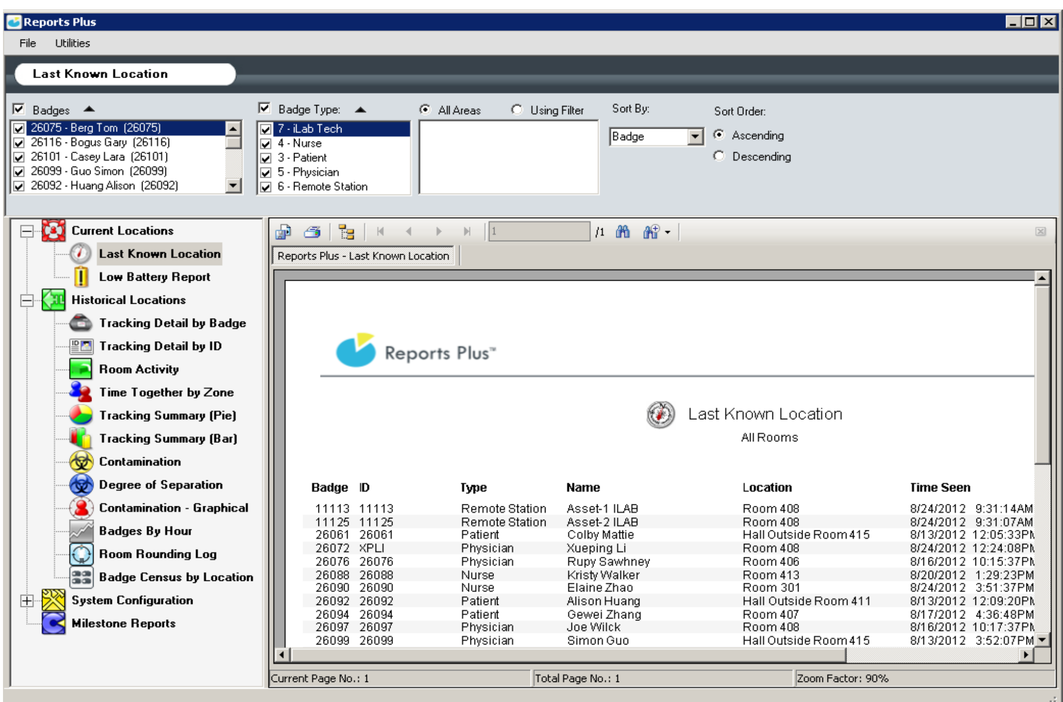


Figure 17: Versus badge location feature

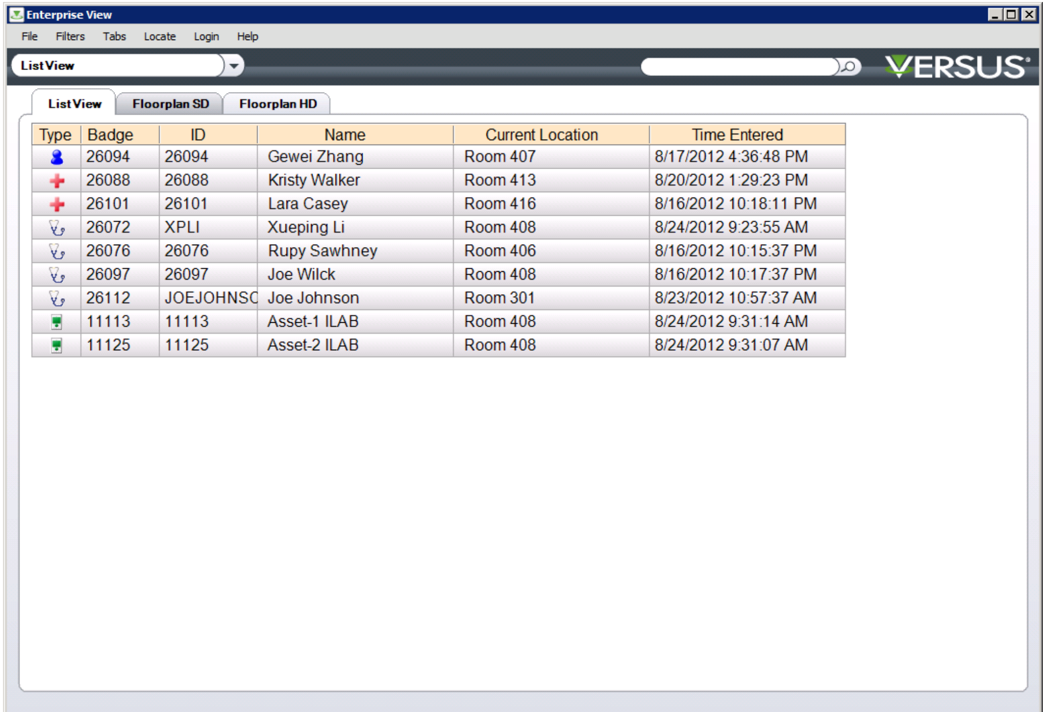


Figure 18: Versus's current location list

Section 5.6 Dashboard

Along with the RTLS and simulation modeling, a user-friendly dashboard will be used to help display information that each individual section will need. The dashboard will display the map of the clinic and current location of everyone being tracked but will also show key metrics and useful information. An overview and front desk version of the clinic can been seen in Figure **2** and Figure **3**. This shows information that helps with the overall progress and flow of the clinic. An alert system and message system would provide information when possible problems might occur and allows each section to communicate to each other.

The providers section's dashboard is shown in Figure 19. Information provided for this section can include data like:

- Which provider and nurse is currently seeing a patient
- Total waiting time for section
- Total waiting time for clinic
- Number of patients waiting for provider
- Provider –to- patient ratio
- Number of scheduled visits left
- Utilization of resources

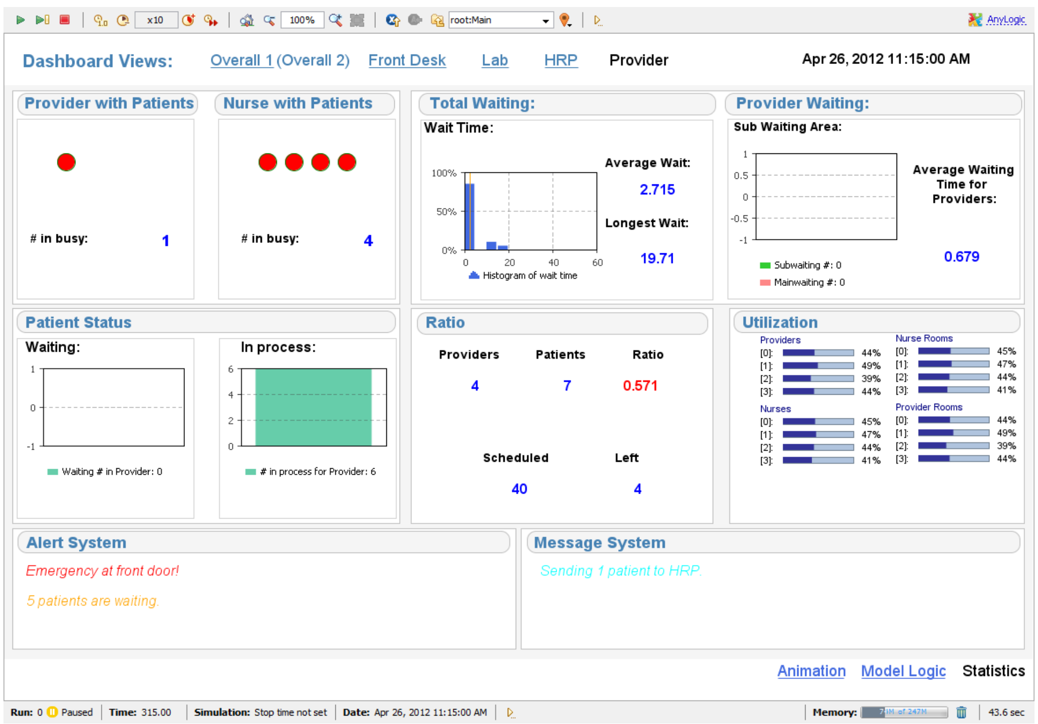


Figure 19: Provider Dashboard

The dashboard for the HRP section is shown in Figure 20. This dashboard could include information like:

- Patient wait times in descending order
- Which psychologists are with patients
- Expected time remaining for procedure

- Psychologist-to-patient ratio
- Number of patients waiting and in progress

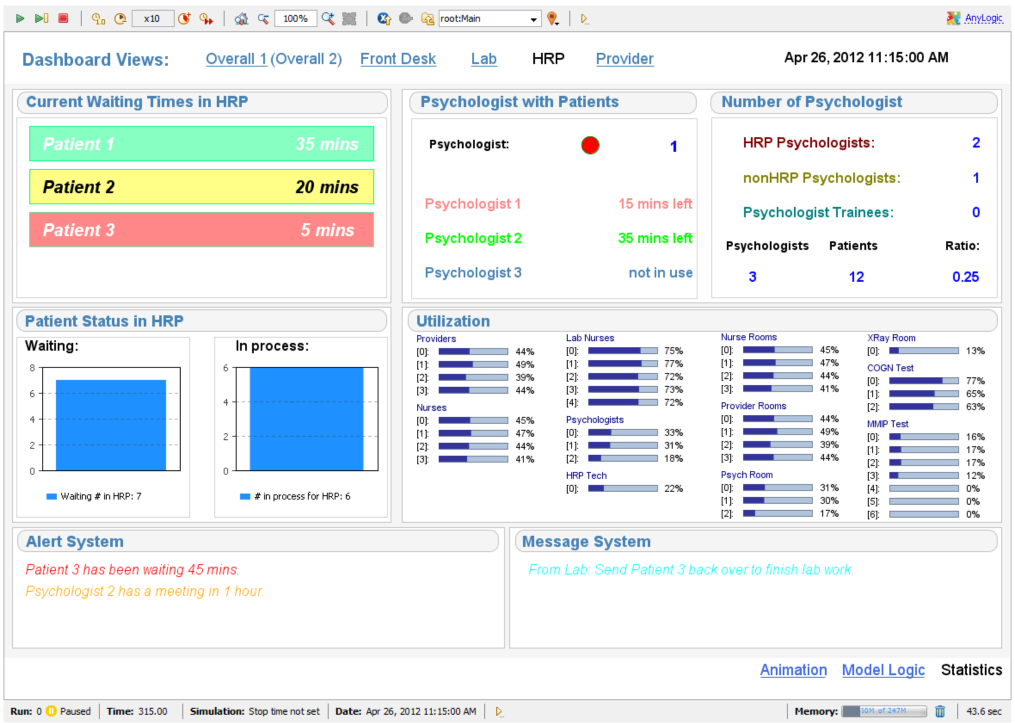


Figure 20: HRP Dashboard

The lab dashboard is shown in Figure 21. This displays information that would help just the lab personal improve their performance and track down patients needed to take lab tests. Key metrics displays on the dashboard could include:

- Patients that need to return to lab and what they are currently doing
- Which lab techs are currently with a patient
- Lab average waiting times
- Number of patients waiting
- Average number of patients waiting
- Average total time in Lab

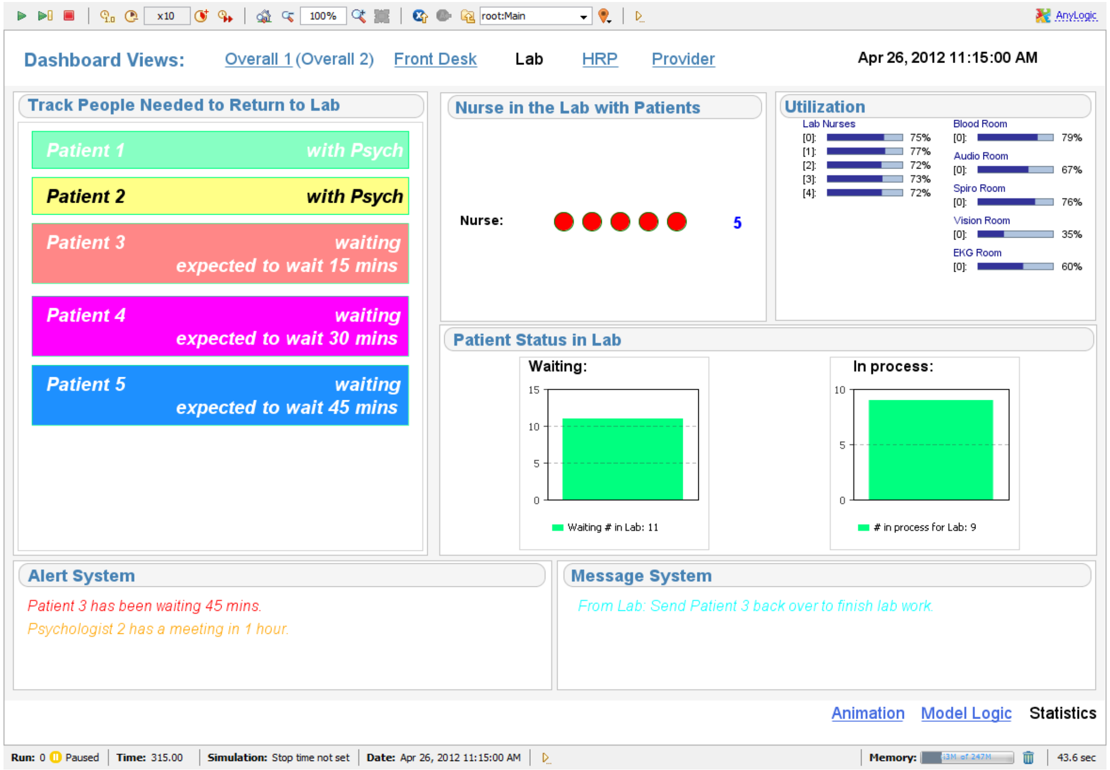


Figure 21: Lab Dashboard

Section 5.7 What-If-Scenarios

Health care providers and operational support staff constantly are required to make split decisions regarding procedures; equipment needs, and staff utilization as conditions change. The use of real time data instead of gut feelings can drastically increase both the level of patient care given and the overall efficiency of the managed facility. At the COC, facility managers make these decisions based on past experiences and their gut feelings that are based on a long understanding of operational protocol. While this method of decision making has worked fairly well over the years it tends to limit the overall decision process and in effect eliminates other decisions that would tend to increase efficiency and the level of patient care. The use of an integrated data assessment system that can provide the facility operators with up to date data regarding patient flow and the procedures that they are being scheduled for would greatly enhance their ability in making decisions regarding the operation of the facility.

One useful tool that this system should have would be a "What-If" analysis feature. This feature would allow the care facility manager see how a decision regarding patient scheduling could impact the overall flow of the clinic based on the current situation and past data trends. Using past data, the simulation model can predict how the clinic might operate when selected patient demands are ran through it. The utilization of these past trends to show how the current situation might be affecting the flow within the facility, the manager can see and predict the future performance of the clinic. The "What-If" feature would allow the manager to test different scenarios to see the impact on the process, and would in turn provide him with valuable information that he could have to increase efficiency of the clinic.

At the COC, a "What-If" function was tested using the initial simulation model. Different scenarios were looked at to see how they would impact the clinic's performance. The clinic currently uses the patient's average total time in system and the average patient wait time as their primary metric for determining the patient flow and procedural utilization. This data set allowed them to develop a bench model of the clinic. From this bench mark data set they ran several different scenarios for a full day to see how they would impact the clinic. Each scenario ran independently of the other in order to preserve the base data. A complete listing of the different scenarios is as follows:

- Down one Provider
- Down one psychologist
- Down one nurse
- Down two lab technicians
- Six additional walk-ins at 2:00

The results of base model and each scenario are illustrated in Table 9. From this table, being down one provider or one psychologist increase the processing times drastically and shows how bad the situation could get if a provider or psychologist couldn't make it for the day. The scenario where there is one less nurse or down two lab technicians shows that the overall processing times were minimally affected and could be attributed to lower clinical costs by being able to schedule less support personnel. The increase in processing times attributed to the physicians being reduce identifies them as a critical resource. This identification of critical resources is need when one models for efficiency gains in an operating facility.

The impact of unexpected changes in patient load is seen when the Six Walk in patients are modeled. This scenario indicates that the clinic could handle this addition case load with minimum impact to the processing times of those who are scheduled. Running the model repetitively would give more precise results and reduce the random variations within the model.

Table 9: Results of the scenarios

	Average Time in System (mins)	**Longest time in System (mins)**	**Average Wait time (mins)**	**Longest patient wait time (mins)**
Base	134	616	53	309
Down 1 Provider	168	641	86	361
Down 1 Psychologist	161	717	82	428
Down 1 nurse	135	617	54	316
Down 2 lab technicians	139	633	58	337
6 additional walk-ins at 2:00	134	609	55	309

The "What-If" feature will allow the manager to give certain inputs and see the results.

Additional scenarios that could be applied are as follows:

- Doctor out for a meeting
- Hiring additional staff
- Having additional equipment available for testing
- Additional patient demand

The “What-If” scenarios could list alternatives to a given set of variables as well as combining different sets of scenarios. This feature is a major tool for helping managers make better data driven decision by seeing they affect different scenarios have on the operations of a facility.

Section 5.8 Improvement Areas

The combination of an RTLS, simulation modeling, dashboard, and all combination features will allow the COC to perform at a higher level of efficiently. The improvement of patient flow through the clinic will help reduce wait and total time in the system. The expected reduction is around 20% and this improvement will allow C-18 workers to return to their job faster and be more productive themselves. The system will show the optimization of key aspects, like number of resources, which will reduce costs as well. By showing data in real time the COC can help create improvements otherwise not available. This system will help eliminate the tendency to make decisions based on gut feeling, and instead provide the clinic staff with a more diverse and accurate means in which to make key operational decisions. This case study will show the benefits of the combination system and how it will improve a healthcare system

Chapter 6 Conclusion

The state of healthcare in the United States is in need of improvement to reduce waste and improve the quality of care for the patients. The escalating costs associated with healthcare are forcing people to postpone or withhold medical attention. Many methods have been implemented to help lower these costs and improve patient flow. The use of simulation modeling and Lean methods has made progress in improving efficiencies; however, these improvements have not been enough to lower cost to an acceptable and more affordable level because of the lack of data that can be gathered and integrated. RTLS are becoming more widely used by the healthcare industry and have developed their own set of benefits to make healthcare more efficient; however, these systems alone still lack the comprehensive tools to make the improvement impact that is needed to justify the overall investment. By combining different systems such as simulation modeling and RTLS health care facilities and providers will afford a tremendous advantage regarding their operating expenses over systems that are deployed independently. Doing this will also allows a healthcare facility track resources in real time and can use data collected by the RTLS to produce more accurate and timely results. These types of systems can aid administrators in quickly identifying bottlenecks within their facilities and can help them deploy needed resources more efficiently with lean methods. All optimization models will reveal how the facility is performing in real time. Managers can use "What-If" analysis to understand how decisions can affect the outcome of different scenarios and help make more data driven decisions. A dashboard that is customizable to each job and user preference, displays information to help make the job easier and stress free. This system can dramatically cut costs, improve patient flow, create a better work environment, and improve patient care.

Chapter 7 Future Work

To continue the progress of project, an operational system must be in place. The project with C-18 must be installed and completed. The system is a trial to show how much of an impact the system will have. Once the system is installed it will be altered to fix any bugs that will arise and adapt to what the system really needs. Once the system is operational, the RTLS part will track patients and show true paths of patients and correct times. For the simulation part to be useful, the RTLS must collect data so the simulation can create input distributions to accurately make predictions. The system will then be alternated by inputs from the staff to become more user-friendly. The displays for the dashboard will be changed to best fit the staff. This gives the system hands on input to how the data should be visually displayed and is major for the success of the system. The system will then look at how it can be more flexible to other facilities for a more plug and play feel.

The math model will also be updated to include other constraints that will enhance the impact it will have. Since patient scheduling is a major concern in healthcare, using the combined system to give inputs on how to structure the math model will help make it more integrated and beneficial. With the math model, RTLS, and simulation model combined, it will incorporate all aspects of what the facility needs to help streamline the scheduling process to minimize wait times and reduce the stress from the workload.

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Appendix

Process Map Description

2.0 Check-In

Patients check in at the front desk. If the patient requires emergency care, priority is given, which will be discussed in further detail in Section 8.0 Emergency.

3.0 X-Ray

X-rays take only 30s – 2min (“You’re done by the time it takes you to take your shirt off.”).

4.0 Lab

The lab does six different tests: Blood, urine, audio, sight, spirometry, and EKG. More detail follows in Sections 4.1 to 4.6.

4.1 Lab – Blood Tests

Drawing and testing blood takes roughly three minutes. All of the lab techs can do this, and when patients are waiting, techs that are not busy with something in one of the other lab stations will assist the techs who are performing these functions.

4.2 Lab – Urine Test

Patients are sent to the restroom with a cup in which they must provide a urine sample. This takes approximately 1-2 minutes, depending on the person. This requires no supervision from the lab techs, which means they are available for other duties while the patient is in the restroom. The first five patients to complete blood and urine tests are sent to HRP, assuming HRP has no queue. If HRP does have a queue, they continue with the lab testing.

4.3 Lab – Audio/Hearing Test

Patient is taken into a hearing testing room with a lab tech while the approximately 4-minute test is performed. If patients have been sent to HRP earlier, they come back at this point and have this test performed; they then proceed through the lab portion of the clinic.

4.4 Lab – Vision

Patients are taken into a room where their vision is tested by a lab tech. This test takes approximately 4 minutes.

4.5 Lab – Spiro Test

Patients are taken into a room where the 5-minute spiro test is conducted by one lab tech. Patients younger than 41 years then either go to HRP (if they need to) or go to see a provider.

4.6 EKG Test

If the patient is over the age of 40, he or she will receive a 10-minute EKG test from one of the lab techs. This is the longest test administered in the clinic. From here, the patient will either go to HRP or go see a provider.

5.0 HRP

Patients go to HRP from the lab (if undergoing a physical) after their urine test is performed, after they have completed all other testing, or if there is a short queue on the HRP side while there is a long queue on the lab side (at the tech's discretion

5.1 HRP – Check-In

Patients sign in and do SIS paperwork, which takes approximately 30 minutes. From here, the patient has no structured destination, as cases are handled on a case-by-case basis.

5.2 HRP - MMPI

Every three years, the patient must take the MMPI (Minnesota Multiphase Personality Inventory), which is administered on one of seven computers in a lab area. This test takes approximately 45 minutes, but some individuals may take longer, depending on their familiarity with computers.

5.3 HRP - COGN Test 1

There are two reasons for employees to take this test. First, if a patient tells an administrator that he or she is on one of a list of certain medications, the administrator may require the employee to take this test. Alternatively, if an employee fails a memory test during a psychological evaluation, the employee may have to take this test. The exam takes roughly 45 minutes, depending on the person's computer ability, and 3 or 4 computer terminals are available if needed.

5.4 HRP - COGN Test 2

As previously, a patient can end up taking this test in one of two ways, by failing the memory test or by having taken certain medications. Patients undergo this test at the psychologist's discretion, based on the failed memory test mentioned above. In rare circumstances, patients may be required to take both COGN Test 1 and 2 in the same visit. The latter exam takes just as long as Test 1 and uses the same 3-4 computer terminals.

5.5 HRP – Psych Evaluation

The patient undergoes an interview with the psychologist. At any point, the psychologist can have the patient take one or both of the cognitive tests; it is entirely at the psychologist's discretion. The interview takes roughly 45 minutes, depending on the patient, and there are 2-4 psychologists available for this process.

After the psych evaluation, a patient can 1) exit the system if he or she did not need to see a provider or if the patient has seen the provider already, or 2) go to see the provider if he or she has already picked up lab results, or 3) can go to the lab, finish any lab work (if needed), and then pick up their lab results to take to the provider if he or she needs to see one.

6.0 Provider

Patients can get directly to the provider from the initial check-in if he or she has been fast-tracked; a patient can also get here from the initial check-in if it is an emergency. Alternatively, a patient could get here from the Lab, assuming he or she has completed the HRP or is not an HRP employee. Finally, employees can get here from HRP assuming they have completed and picked up the results of their lab evaluation.

6.1 Provider – Main Waiting Area

Patients must wait in this area to be seen by one of the nurses.

6.2 Provider – Nurse

The nurse evaluates the patient and makes the determination as to whether the employee should be fast-tracked (can be returned to work in a reasonable manner of time) or a non-fast-tracked employee (needs a physical or other time-consuming procedure).

6.3 Provider – Fast-Track Waiting

Waiting rooms are divided to prevent conflicts between employees over waiting times. The FT waiting room is in the main waiting room of the facility near the initial check-in desk.

6.4 Provider – Non-Fast-Track Waiting

This waiting room is the sub-waiting room next to the nurses' stations. Individuals getting physicals tend to be in this category. Priority is given to the individuals in fast track.

6.5 Provider

Evaluates the patient's test results and performs necessary checks and tests.

*One provider is designated to only see fast-track patents to ensure a quick visit for these patients.

7.0 END

Employee exits the system.

8.0 Emergency

Patients come into the clinic with true medical emergencies that require immediate attention (most commonly chest pain that may be a heart attack).

8.1 Examination

The administrator at the front desk of the initial check-in station will determine if there is an emergency situation. If this situation is detected, a provider and nurse will be notified immediately to assist the patient. The nurse and provider are to focus solely on that particular patient. The nurse and provider assess the situation and decide the appropriate course of action. If the patient is in need of hospital treatment, the provider will accompany the patient in the ambulance to a hospital of the patient's choice, or, if the provider determines that time is of the essence, the provider's choice. The provider may be able to fix the situation in the clinic, and if that is the case, the patient will not go to the hospital at this time. Emergency situations can range from broken bones to lacerations to potential heart attacks.

Other Processes

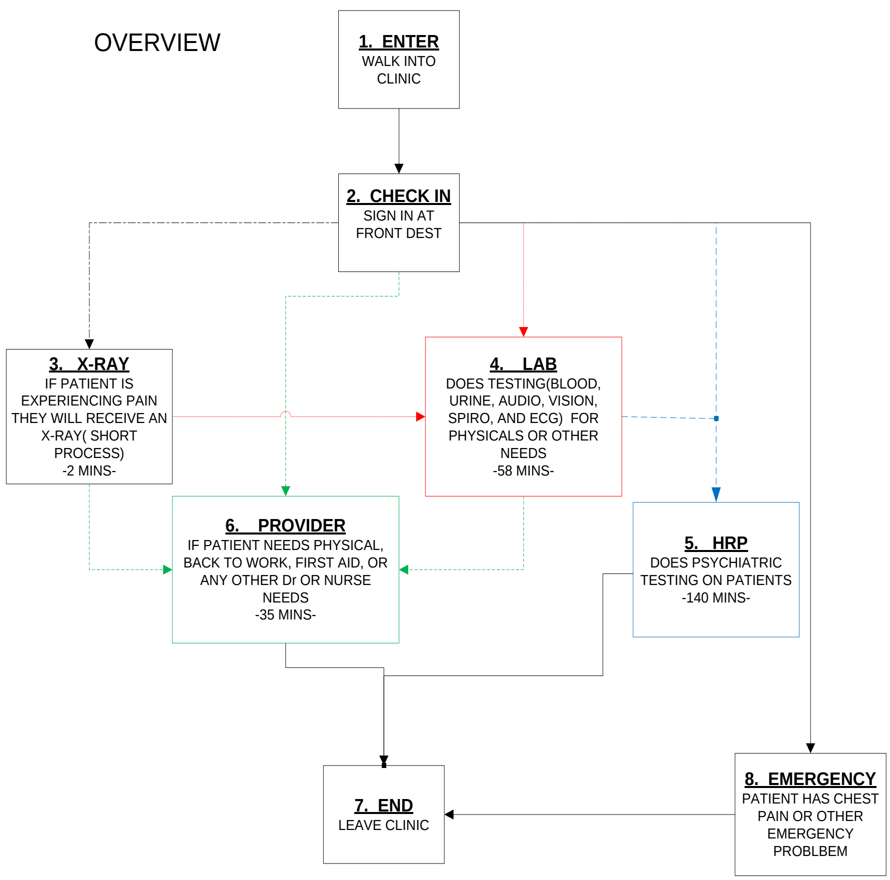
COC offers other exams, tests, and processes but those are not listed in this Data Dictionary. The other processes include but are not limited to

- Allergy Shots (performed from 1 -2 p.m. by nurse)
- Eye Exam
- Drug testing (Performed in Lab)
- Alcohol breath testing (Performed in Lab)
- Respiratory

- Physical Therapy (patient is seen by a nurse upon first visit; otherwise only seen by physical therapist)

These processes were excluded because of short process times or because the process is not related to other processes that would keep the patient in the clinic longer.

COC Process Map Flow



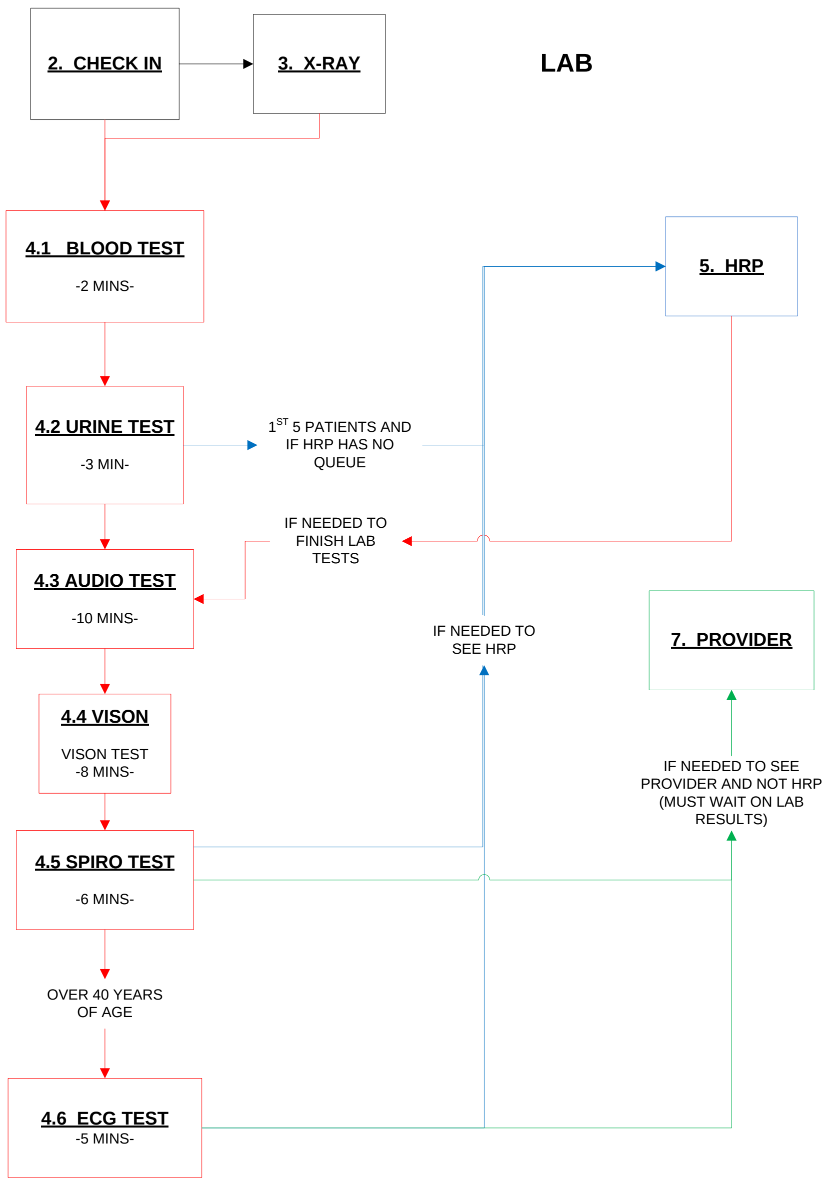
KEY

RED- FLOW INTO LAB

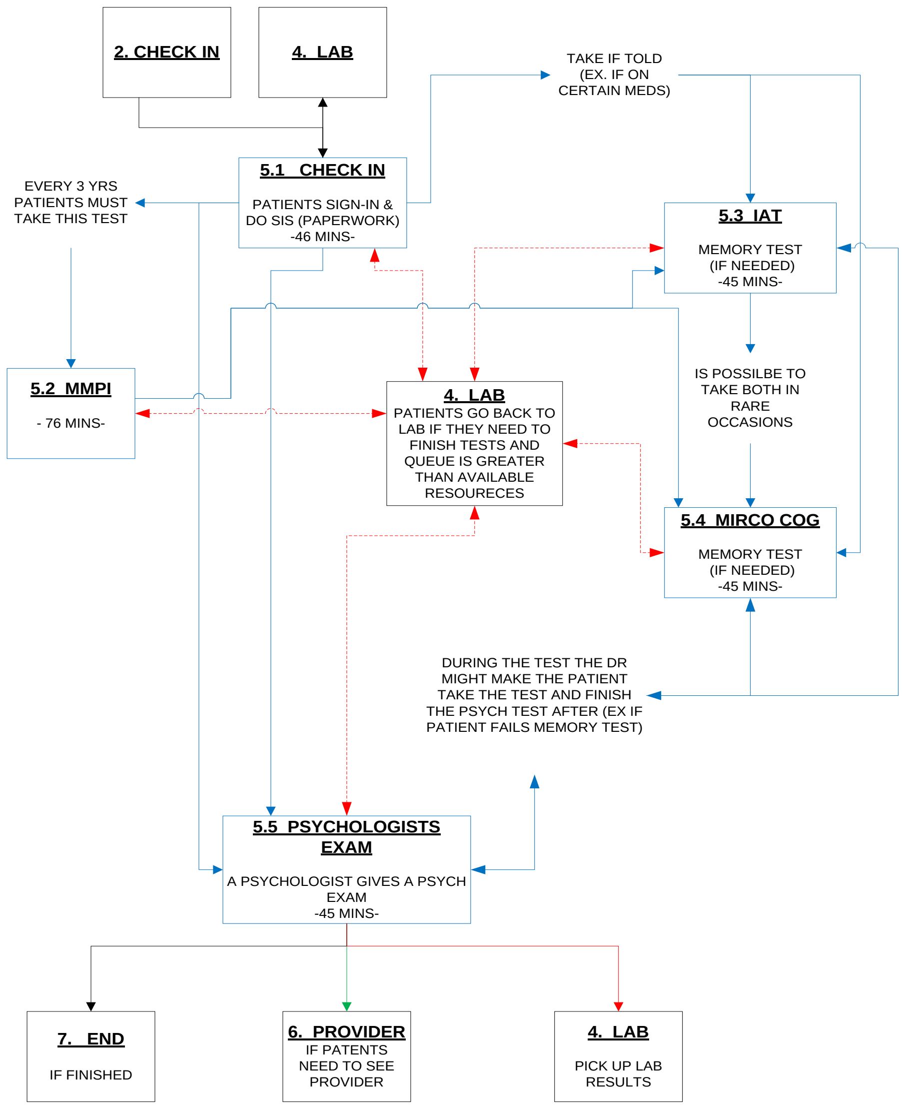
BLUE- FLOW INTO HRP

GREEN – FLOW INTO PROVIDER

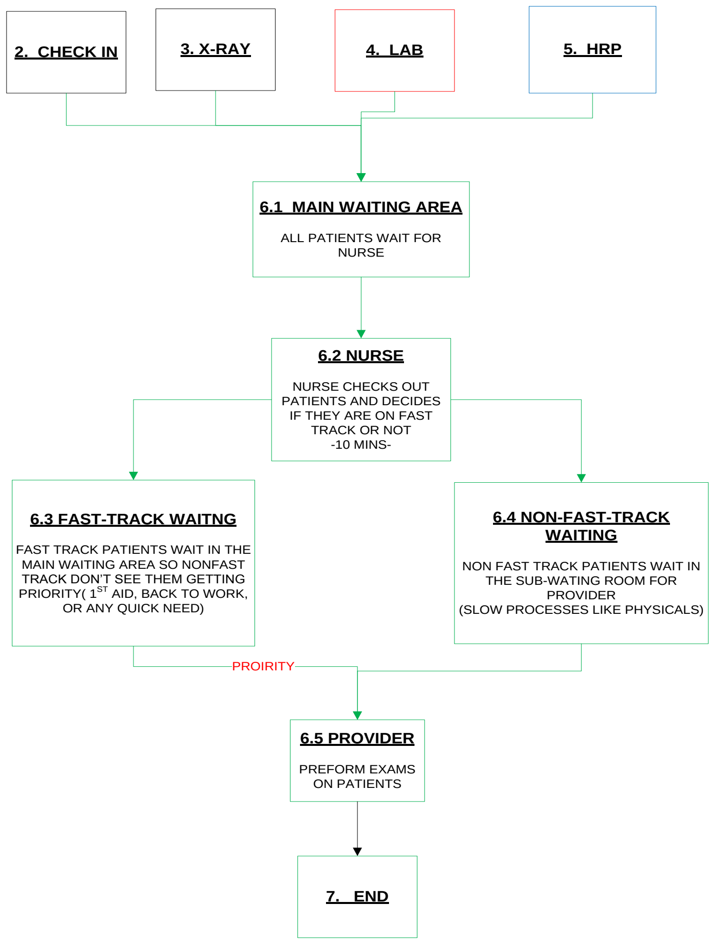
BLACK -OTHER FLOW


LAB
2. CHECK IN
3. X-RAY
4.1 BLOOD TEST
-2 MINS-
5. HRP
4.2 URINE TEST
-3 MIN-
1ST 5 PATIENTS AND IF HRP HAS NO QUEUE
IF NEEDED TO FINISH LAB TESTS
4.3 AUDIO TEST
-10 MINS-
IF NEEDED TO SEE HRP
7. PROVIDER
4.4 VISON
VISON TEST
-8 MINS-
IF NEEDED TO SEE PROVIDER AND NOT HRP (MUST WAIT ON LAB RESULTS)
4.5 SPIRO TEST
-6 MINS-
OVER 40 YEARS OF AGE
4.6 ECG TEST
-5 MINS-

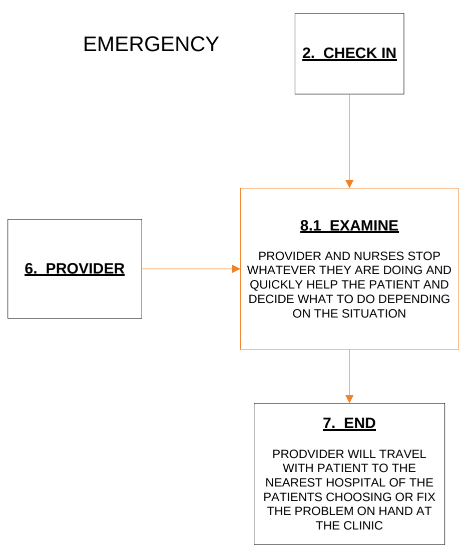
HRP


2. CHECK IN
4. LAB
TAKE IF TOLD
(EX. IF ON
CERTAIN MEDS)
EVERY 3 YRS
PATIENTS MUST
TAKE THIS TEST
5.1 CHECK IN
PATIENTS SIGN-IN &
DO SIS (PAPERWORK)
-46 MINS-
5.3 IAT
MEMORY TEST
(IF NEEDED)
-45 MINS-
5.2 MMPI
- 76 MINS-
4. LAB
PATIENTS GO BACK TO
LAB IF THEY NEED TO
FINISH TESTS AND
QUEUE IS GREATER
THAN AVAILABLE
RESOURECES
IS POSSILBE TO
TAKE BOTH IN
RARE
OCCASIONS
5.4 MIRCO COG
MEMORY TEST
(IF NEEDED)
-45 MINS-
DURING THE TEST THE DR
MIGHT MAKE THE PATIENT
TAKE THE TEST AND FINISH
THE PSYCH TEST AFTER (EX IF
PATIENT FAILS MEMORY TEST)
5.5 PSYCHOLOGISTS
EXAM
A PSYCHOLOGIST GIVES A PSYCH
EXAM
-45 MINS-
7. END
IF FINISHED
6. PROVIDER
IF PATENTS
NEED TO SEE
PROVIDER
4. LAB
PICK UP LAB
RESULTS

PROVIDER



EMERGENCY



Vita

Colby Mattie was born and raised in Lafollette, TN to the parents of Stan and Jane Mattie. He has an older brother named Adam Mattie and a younger sister named Emily Mattie. During grammar school he attended Valley View Elementary school, Lafollette Middle School, and Campbell County High School. After graduation high school Colby enrolled at the University of Tennessee, Knoxville, to study Industrial Engineering. He obtained his Bachelors of Science from the University of Tennessee, Knoxville, in December 2011 in Industrial Engineering. The following semester he enrolled in the dual MBA and MS Industrial Engineering program at the University of Tennessee, Knoxville, and took an assistantship position in the Industrial Engineering department. Colby will graduate with his MBA and MS in Industrial Engineering in the summer of 2013.